JOURNAL OF ANIMAL SCIENCE

Published Quarterly

by the

American Society of Animal Production

AUGUST

1947

Volume 6 Number 3

CONTENTS

	Page
The Comparative Efficiency of Single Versus Three-Day Weights of Steers, R. E. Patterson	237
Birth Weight as a Criterion of Selection in Beef Cattle, W. M. Dawson, Ralph W. Phillips and W. H. Black	247
Application of Water to the Body Surface of Water Buffaloes and Its Effect on Milk Yield, K. C. Sinha and F. C. Minett	258
Effectiveness of Selection for Efficiency of Gain in Duroc Swine, G. E. Dickerson and J. C. Grimes	265
A Study of Factors Affecting Survival from Birth to Weaning and Total Weaning Weight of the Litter in Swine, L. M. Winters, J. N. Cummings, and H. A. Stewart	288
The Heritability of Some Factors Affecting Productivity of Brood Sows, J. N. Cummings, L. M. Winters and H. A. Stewart	297
The Effect of Thiouracil on Efficiency of Gains and Carcass Quality in Swine, W. N. McMillen, E. P. Reineke, L. J. Bratzler and M. J. Francis	305
Nicotinic Acid Deficiency and Nicotinic Acid Requirement of Young Pigs on a Purified Diet, W. C. Powick, N. R. Ellis, L. L. Madsen and C. N. Dale	310
The Comparative Value of a Carotene Concentrate, Alfalfa Meal, and a Fish Liver Oil in Maintaining the Vitamin A Content of the Blood and Liver of Fattening Lambs, J. A. Hoefer and Willis D. Gallup	325
The Effect of Cobalt on Growth and Certain Blood Constituents of Sheep, A. L. Pope, P. H. Phillips, and G. Bohstedt	334
The Influence of Protein Source Upon Nitrogen Retention by Sheep, G. P. Lofgreen, J. K. Loosli and L. A. Maynard	343
Content and Digestibility of Morning and Evening Cuttings of Alfalfa, William H. Adolph, H. A. Macdonald, Hui-Lan Yeh and G. P. Lofgreen	348
Impairment in Nutritive Value of Corn Grain Damaged by *Nigrospora Oryzae*, H. H. Mitchell, Jessie R. Beadles, Benjamin Koehler and George H. Dungan	352
News and Notes	359

Contents of previous issues of the JOURNAL OF ANIMAL SCIENCE are indexed in the Agricultural Index which is available in most libraries, and in the November issue of each complete volume of the JOURNAL.

THE COMPARATIVE EFFICIENCY OF SINGLE VERSUS THREE-DAY WEIGHTS OF STEERS

R. E. PATTERSON[1]

Texas Agricultural Experiment Station

SINCE the results of the extensive work of Lush *et al.* (1928) on the "experimental error" of weights in cattle were published, it has become a common practice to weigh experimental cattle on three consecutive days at the beginning of the test and again on three consecutive days at the end of the test. Such a practice was recommended as a standard procedure in 1931 by a committee of the American Society of Animal Production (1932) on methods of investigation. This procedure has also been followed in weighing experimental swine and sheep. In certain types of experimentations, however, it is frequently considered impractical to weigh the animals on more than one day. This is especially true in pasture grazing work where weighing involves considerable time, labor, and abuse of the animals. It is also noteworthy that all sales of cattle at market are made on the basis of single weights.

There has been but little published work on the comparative efficiency of multiple over single-day weights. Lush and Black (1926) concluded that the error in three-day weights is only 57 percent that of a one-day weight. Lush *et al.* (1928) stated that weighing on two additional days eliminated about 42 percent of the error contained in a one-day weight. They further stated that a "three-day accuracy for comparison with the control lot may be attained by using three times as many animals in each lot." Hale and Godbey (1935) found with pigs that incorrect interpretations due to inaccuracies in weight can be avoided by decreasing the probability. Thus, when using gains based on one-day weights, differences may be safely interpreted by using a t value of 2.2 (18 degrees of freedom) for the lower level of significance. They considered that the size of the sampling error does not minimize the influence of the error due to inaccuracies in weights. Hazel (1938), also working with pigs compared the efficiency of single versus three-day weights and concluded that the practical value of weighing more than once is negligible. His conclusion is based upon the relatively small standard deviation due to inaccuracy of weight as compared to the sampling error.

In a recent paper Bean (1946) found in swine that the standard error of

[1] The author wishes to express his appreciation to J. M. Jones, Chief, Division of Range Animal Husbandry, Texas Agricultural Experiment Station; F. E. Keating, Superintendent, Big Spring Station, Bureau of Plant Industry, U. S. Department of Agriculture; and to W. H. Black, Senior Animal Husbandman, Bureau of Animal Industry, U. S. Department of Agriculture, for their permission to use the data of the Big Spring feedlot steers. Indebtedness is also acknowledged to D. A. Savage, Senior Agronomist, Bureau of Plant Industry, U. S. Department of Agriculture, for furnishing the weights of the range pasture-grazed steers used in this study.

the mean of first-day weights was less than that of the three-day average in 19 out of 23 weight classes. He concluded that errors are actually introduced into the results by using three-day averages and recommended the discontinuance of the practice of taking weights on more than one day.

Description of Data

The data used in this study are composed of three general types: (1) feedlot steers; (2) summer pasture-grazed steers; and, (3) winter pasture-grazed steers. The data of the first type are the three-day initial and three-day final weights of 402 steers on feedlot tests conducted in cooperation with the Texas Agricultural Experiment Station at the United States Dry Land Field Station, Big Spring, Texas. These data were collected over a period of nine different years, from 1935 to 1946. Those of the second and third type are the three-day initial and three-day final weights from part of the animals used in the 1945 summer and the 1945–46 winter grazing tests by the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, at the United States Southern Great Plains Field Station, Woodward, Oklahoma. Weights from 208 steers on the 1945 summer tests and from 186 steers on the 1945–46 winter tests were included in this study. The feedlot and winter range pasture-grazed steers were weanlings at the initial weighing, while the summer range pasture-grazed steers were full yearlings at initial weighing.

The Big Spring steers were weighed on scales that were read to the nearest 2-pound unit, while the Woodward steers were weighed to the nearest 5-pound unit.

Sources of Variation

There are three primary sources of variation in three-day weights of cattle. First, variation results when the average of one day's weighing is different from the averages of other days. The variance for differences between days measures that tendency for weights of all animals one day to be different, either higher or lower, from those of another day. Pronounced changes in temperature from one day to another, excitement of a previous weigh day, change in amounts of feed, change in time of day of weighing during the weighing period are some of the factors that may cause variations of this type.

The second source of variation is that due to differences between animals. This variation is the experimental error. Its variance is a measure of the genetic differences between animals and differences caused by differences in age, if different ages are represented. It also includes any differences of environmental conditions that affected the animals differentially prior to the weighing period.

The third source of variation is that which cannot be explained by differences due either to days or to animals. It is the residual or interaction variation between days and animals and will be described in this paper under the term residual. This type of variation may be caused by differences in fills of the individual animals during the several weighing days but is not reflected in the average for all animals in each of the several days. It also includes errors resulting from misreading the scales and any variable inaccuracies in the scales themselves. Such variation may be analogous to technique error in other types of experiments.

In final weights and gains there is another possible source of variation, that due to differences between groups or lots. Such a variation would be the result of the effects of the treatments. In initial weights there was no justification for segregation of lot variation; in fact, the animals were assigned to the lots in such a manner that the variations for lots were smaller than would be expected on the basis of random allotment.

In the Big Spring data weights from steers on experiments in different years were included, bringing into this set of data another possible source of variation.

For the present analysis, interest lay primarily in the variations due to animals and to the residual. For the initial weights in the Big Spring data these variances were calculated on an intra-year basis, while the final weights and gains of the same animals were calculated on an intra-year and intra-group basis. In both sets of Woodward data the variances for final weights and gains were calculated on an intra-group basis. This obviated the possibility of inclusion of variations due to years and groups that might be confounded with the animal and residual variances as a result of disproportionate numbers.

Analysis of Data and Discussion

Absolute Weights

In tables 1 and 2 are shown the mean squares for animals and residuals for initial and final weights of the feedlot steers at Big Spring and the range pasture-grazed steers of the Woodward Station.

In agreement with Lush *et al.* (1928) the residual mean square (their "experiment error") for both initial and final weights is very small as compared to the mean square for animals. The square root of these mean squares gives the standard deviations for the two sources of variation for each set of data. The standard deviations of the residual are, in reality, the standard errors of individual weights for the three sets of data. These are the sizes of errors expected in single-day weights due to the residual type of variation.

In comparing tables 1 and 2, it is noted that the residual variance is some-

what larger for final weights than for initial weights in each type of data. However, the means for the final weights are also larger than the means for the initial weights, resulting, therefore, in coefficients of variations for final weights that are actually less than those for initial weights in each case.

When the absolute values of the residual standard deviations for initial

TABLE 1. ANIMAL AND RESIDUAL VARIATIONS FOR INITIAL WEIGHTS OF FEEDLOT AND RANGE PASTURE-GRAZED STEERS

Source of data	Source of variation	d.f.	Mean square	Estimate of (σ) pure variance
Big Spring	Animal	393	6,608.03	$\sigma_a^2 = 2193.95$
Big Spring	Residual	786	26.19	$\sigma_r^2 = 26.19$
Woodward (summer 1945)	Animal	207	4,126.02	$\sigma_a^2 = 1361.17$
Woodward (summer 1945)	Residual	414	42.52	$\sigma_r^2 = 42.52$
Woodward (winter 1945–1946)	Animal	185	11,463.82	$\sigma_a^2 = 3808.49$
Woodward (winter 1945–1946)	Residual	370	38.35	$\sigma_r^2 = 38.35$

TABLE 2. ANIMAL AND RESIDUAL VARIATIONS FOR FINAL WEIGHTS OF FEEDLOT AND RANGE PASTURE-GRAZED STEERS

Source of data	Source of variation	d.f.	Mean square	Estimate of (σ) pure variance
Big Spring	Animal	353	14,747.91	$\sigma_a^2 = 4899.94$
Big Spring	Residual	706	48.09	$\sigma_r^2 = 48.09$
Woodward (summer 1945)	Animal	194	6,723.12	$\sigma_a^2 = 2212.99$
Woodward (summer 1945)	Residual	388	84.14	$\sigma_r^2 = 84.14$
Woodward (winter 1945–1946)	Animal	174	10,350.95	$\sigma_a^2 = 3433.71$
Woodward (winter 1945–1946)	Residual	348	49.81	$\sigma_r^2 = 49.81$

and final weights are compared, it will be seen that the error in weighing large steers is very little greater than in weighing smaller ones, when the large differences in mean weights are considered.

In practice, the problem is to compare the differences between two or more groups. Suppose that this comparison is to be made on the basis of their final weights. It is granted that this is an infrequent practice which may lead to false interpretations, as the animals are not usually randomly assigned to the lots at the outset of the experiment. The variance that should be used to test the significance of the differences between groups is that for between animals. The mean square for differences between animals where three final

weights are taken includes, in addition to three parts of a component due to animals, one part of the residual mean square. From this fact it must be granted that the size of the residual or weighing errors is considered in the significance test. However, as there are two different components that constitute the variance for animals, it is possible to calculate their importance relative to each other. The details of this procedure are well presented by Snedecor (1946).

The mean squares for animals in tables 1 and 2 may be represented by the following equation: $3\sigma_a^2+\sigma_r^2$, where σ_a^2 is a component of "pure" variance due to differences between animals and σ_r^2 is a component due to the residual variation. This equation when divided by three gives the variance between animals based upon the average of three weights and is then comparable to the variance between animals based upon single-day weights. The equation for the variance between animals based on single-day weights is $\sigma_a^2+\sigma_r^2$. Single-day weights include, therefore, three times as much residual variation as three-day weights. It is further seen that the proportion of the residual variance included in the sampling error (between animals) decreases as the number of weights is increased.

It might be of some interest to point out that the arithmetic average of the sums of squares for the three separate day weights is greater than the sum of squares for the three-day averages by one-third the sum of squares of the residual. The variance for the average of three-day weights would be considered the more reliable, provided there is no significant difference between the variance for the different days. Bean (1946) concluded that there were significant differences in variabilities in the several weight days for pig weights. However, no such significances were found in the cattle data included in this study.

As the mean square for residual is an estimate of σ_r^2 and the mean square for animals with three-day weights is an estimate of $3\sigma_a^2+\sigma_r^2$, it is possible to estimate the value for σ_a^2. As a numerical example, consider Big Spring values in table 2. The parameter σ_r^2 is estimated by 48.09 and $3\sigma_a^2+\sigma_r^2$ is estimated by 14,747.91. Solving for σ_a^2 gives a value of 4,899.94. As stated above, $\sigma_a^2+\sigma_r^2$ is the equation for the mean square of animals based upon single-day weights. Substituting in this equation, 4948.03 is obtained. A comparable value for three-day weights is 4915.97, or $\sigma_a^2+\sigma_r^2/3$. Thus the mean square for animals is larger when based upon single weights than when based upon three-day weights. It is larger by two-thirds of the residual variance. The mean square for animals is, therefore, reduced 32.06 as a result of the two extra weighings. This represents a reduction of 0.65 percent. Stated another way, this means that the same degree of precision of a three-day weight should be expected from single-day weights if the number of

animals is increased by 0.65 percent. For example, greater efficiency would be expected of data from 11 animals with single-day weights than of data from 10 animals with three-day weights. It would seem much more practical to forego the additional precision altogether or otherwise increase the number of animals on the tests. Correspondingly small increases in efficiency from extra weighings are found for each of the two sets of Woodward data. These are 2.44 percent for summer final weights and 0.95 percent for winter final weights.

Gains

In most experiments with groups of cattle, the plan is usually to compare one lot against another on the basis of the differences in animal gains, rather than their absolute weights. When probability statements are made, they

TABLE 3. ANIMAL AND RESIDUAL VARIATIONS FOR GAINS OF FEEDLOT AND RANGE PASTURE-GRAZED STEERS

Source of data	Source of variation	d.f.	Mean square	Estimate of (σ) pure variance
Big Spring	Animal	353	6004.57	$\sigma_a^2 = 1978.27$
Big Spring	Residual	706	69.75	$\sigma_r^2 = 69.75$
Woodward (summer 1945)	Animal	194	2849.93	$\sigma_a^2 = 912.44$
Woodward (summer 1945)	Residual	388	112.60	$\sigma_r^2 = 112.60$
Woodward (winter 1945–1946)	Animal	174	2322.38	$\sigma_a^2 = 742.25$
Woodward (winter 1945–1946)	Residual	348	95.64	$\sigma_r^2 = 95.64$

generally are based upon the variation of gains of the individual animals and such gains are usually based upon three-day weights, i.e., the differences between the average of three initial weights and the average of three final weights. As with absolute weights the object of the present analysis is to compare the efficiency of an experiment where the gains are based upon single-day weights against one whose gains are from three-day weights.

There is a very simple algebraic relationship between the two absolute weights and the gains derived from them. The equation is as follows:

$$s_g^2 = s_{a1}^2 + s_{a2}^2 - 2s_{a1}s_{a2}r_{a1a2}$$

where g, *a*1 and *a*2 represent gain, initial weight and final weight, respectively. It may be noted from this equation that the size of the variance of gains becomes smaller as the size of the correlation between initial and final weights increases.

Table 3 shows the variance and the component estimates for animals and

residual for gains from the Big Spring and the winter and summer Woodward steers. As with absolute weights, the variation of gains for between animals is considerably larger than that for residual. However, residual variation of a single gain is greater than that for either of the absolute weights. This results from the fact that the standard error of the differences is equal to the square root of the sum of the squares of the standard errors of the initial and final weights, considering, of course, that there is no correlation between the errors in the initial weights and errors in final weights.

The variance of the three-day weight gains from the Big Spring steers is equal to $\sigma_a^2+\sigma_r^2/3=6004.57/3=2001.52$. This is the value that would be obtained for the mean square of the gains based upon the average of three initial and three final weights. The value to be expected from single-day weight gains would be the average mean square of the three individual sets of gains or $\sigma_a^2+\sigma_r^2=1978.27+69.75=2048.02$. The reduction in variance due to the four extra weighings is $2048.02-2001.52=46.50$. The percent reduction is 2.27 percent. This means that a greater precision would be expected from 11 animals weighed once than from 10 animals weighed on three consecutive days. The same degree of precision can be obtained, therefore, by 2.27 percent increase in the number of animals in the test and obtaining only single-day weights.

The efficiency of an experiment thus may be increased by decreasing the variance of the "error mean square" or animal variance. This may be accomplished by reducing the quantity of variance contributed by one or more of the components that make up this variance. It is possible to reduce the weighing error (residual component) contained in the variance for animals by increasing the number of consecutive weighings. Thus, the variance for gains based upon three-day weights has only one-third as much of this type of error as single-day weights. For example, in gains from the Big Spring data the standard error of a single-day weight, as shown in table 3, is 8.35 pounds. The corresponding standard error for a weight based upon the average of three weights is $8.35/\sqrt{3}=4.82$. This means that a three-day weight has only 57.7 percent as much residual error as a single-day weight. This, of course, is a considerable reduction *in this type of error* resulting from the extra weighings. The important consideration is, however, to show how much the removal of this type of error reduces the mean square for "animals." As this mean square from single-day weights is an estimate of $\sigma_a^2+\sigma_r^2$, the decrease will have to come from the reduction in the proportion of σ_r^2. This mean square for between animals with three weights is an estimate of $\sigma_a^2+\sigma_r^2/3$ reducing, therefore, the residual variance contained in this source by one-third. Thus, $s_a^2=1978.27$, and $s_r^2=69.75$, which when combined give the mean square for between animals with single-day weights and equal

2048.02. The value of the mean square for the same source but with three-day weights becomes 2001.52 or a decrease of 2.27 percent in the variance of the mean, as previously found, resulting from the extra weighings. By the same procedure the standard error squared for two-day weights was 2013.15, which represents 1.70 percent reduction over single-day weights. By comparing the three-day weights and the two-day weights, it was found that the reduction of the standard error due to the extra weights was only 0.58 percent. From such considerations it may be stated that the size of the sampling errors (variance due to animals) does not minimize the errors due to inaccuracies in the weighing, but it does alter the relative amount of influence.

The reduction in the variance for animals in the summer Woodward data, due to the extra weighings, was from 1025.04 for single-day weights to 949.98 for three-day weights. This represents a decrease of 7.32 percent as a result of the extra weighings. The reduction in the mean square for two-day weights was 5.49 percent. The reduction of three-day weights over two-day weights was, therefore, 1.94 percent.

The variance for animals in the winter Woodward data was 837.89 for single-day weights and 774.13 for three-day weights or 7.61 percent reduction due to the extra weighings. The reduction of two-day over one-day weights was 5.71 percent, while the reduction of the three-day weights over two-day weights was 2.02 percent.

The standard error squared of the mean for animals may also be reduced by increasing the number of animals, as indicated above. For example, using the Big Spring data (table 3), the mean square of the gains from single-day weights is an estimate of $\sigma_a^2+\sigma_r^2$, which, when divided by 100, gives 20.48. This equals the standard error squared of the mean, based upon 100 animals. If three extra animals are added, the standard error squared would on the average be reduced to 19.88, as the new divisor becomes 103 instead of 100. This is to be compared with the standard error squared for the average of three-day weights of 100 animals, which is 20.02 or ($s_a^2+s_r^2/3$ divided by 100). The latter value is 0.70 percent greater than that from 103 steers with single-day weights. This means that data from 103 steers with single-day weights would be expected to be slightly more efficient than data from 100 steers with three-day weights.

In comparing the three sets of data, it is noted that the variance of animals for the Big Spring data was least affected by the multiple weights. There are two reasons for this. First, the weighing error (residual) was slightly smaller, both in the initial and final weights, and consequently in gains also. Second and by far the most important, the average gains of the Big Spring steers were considerably larger than those of either of the pasture-grazed groups, resulting in a larger pure variance for animals. If the residual vari-

ance is relatively constant, as was the case in these data, the larger the variance for animals the smaller the proportion of residual included in it. Considering a constant relative variability in gains among groups, the residual variance may become an important component of the animal variance if the mean gains are small. Conversely, it becomes less important as the mean gain increases in size or as the absolute variability among the animals increases.

It can be concluded from these data that there is only a slight decrease in the variance of the absolute weights resulting from multiple weights. Only under exceptional circumstances could it be considered that multiple weighing is an economical method by which to increase the precision of an experiment. This applies to all absolute weights including the weanling weights and later their final weights as well as the initial and final weights of animals older than weanlings.

Although the residual variance of gains is the sum of the residual variances of initial and final weights, there is still only a slight increase in efficiency resulting from multiple weighings when gains from feedlot steers are considered. The increase in efficiency from multiple weighings for range pasture-grazed steers is somewhat greater, but even here it is questionable whether the extra weighings can be justified on the basis of their increase in precision. There is only a small increase in precision of gains based upon three-day weights as compared to two-day weights. Where the average or the variation in gains is small, there may be some argument for obtaining more than single-day weights.

Summary and Conclusions

Variances for initial and final weights and for gains of 402 feedlot steers and 394 range pasture-grazed steers were segregated into their components. The sources of variation considered of primary interest in this analysis were the variations for between animals and for residual.

With absolute final weights it was found that in the Big Spring data the mean square for between animals can be reduced, as a result of two extra weights, by only 0.65 percent. Reduction in the mean square of the final weights of the Woodward summer grazed steers was 2.44 percent. In the winter grazed steers the reduction was 0.95 percent.

The mean square for gains in the Big Spring steers is found to be reduced, as a result of four extra weighings, by 2.27 percent. Comparable figures for the Woodward summer and winter data are 7.32 percent and 7.61 percent, respectively. The sizes of the residual variation for gains in the three sets of data were 8.4, 10.6, and 9.8 pounds for Big Spring data, Woodward summer and winter data, respectively.

It is possible to reduce the size of the standard error of the mean for between animals by increasing the number of animals in the test. In all three sets of data 11 animals with single-day weights is more efficient, as judged by a smaller standard error for animals, than 10 animals with three-day weights. This applied to gains as well as to absolute weights.

There is the possibility in many experiments that the efficiency of the data can be increased more economically by increasing the number of animals on the tests rather than increasing it by resorting to multiple weights. In certain experiments it would seem more practical to forego the additional precision resulting from extra animals, altogether, and apply the money thus saved on other experiments or other phases of the same experiments.

Literature Cited

Bean, H. W. 1946. Single Weight versus a Three-Day Average Weight for Swine. JOURNAL OF ANIMAL SCIENCE, 5: 30–35.

Hale, Fred and Godbey, C. B. 1935. The Relative Accuracy of One-Day and Three-Day Weights of Pigs. Amer. Soc. Anim. Prod., Proc., pp. 119–122.

Hazel, L. N. 1938. A Statistical Study of the Accuracy of Swine Weights. A thesis submitted for the degree of Master of Science, Texas Agric. and Mechanical College.

Lush, J. L. and Black, W. H. 1926. How Much Accuracy is Gained by Weighing Cattle Three Days instead of One at the Beginning and End of the Feeding Experiment. Amer. Soc. Anim. Prod., Proc. (1925–26), pp. 206–210.

Lush, J. L., Christensen, F. W. and Black, W. H. 1928. The Accuracy of Cattle Weights. Jour. Agric. Res., 36: 551–580.

Snedecor, George W. 1946. Statistical Methods Applied to Experiments in Agriculture and Biology. The Iowa State College Press, 4th Ed., pp. 48[illegible].

BIRTH WEIGHT AS A CRITERION OF SELECTION IN BEEF CATTLE

W. M. Dawson, Ralph W. Phillips and W. H. Black
United States Department of Agriculture[1]

IN THE selection of breeding animals it is important to determine their prospective value at an early age. This is especially true in the case of cattle, where, under practical conditions, most of the males are castrated by weaning time. A study of birth weights as a measure of the prospective value of the calf is therefore justified since it is one of the first measures that can be obtained and also one of the easiest to record with reasonable accuracy.

The present study is based on analyses of data from the beef Shorthorn herd at Beltsville, Maryland, to determine some of the factors affecting birth weight of the calves, heritability of birth weight, and relation of birth weight to rate of growth of calf and economy of gain in the feed lot.

Material

Birth weights were available on 402 calves born as singles. There were two sets of twins, but these were not used in this study. The ages of the cows at the birth of all the calves were known. For 71 steer calves the weight of the dam just after calving was available and for 307 calves the length of the gestation period could be calculated. The calves were born from 1930 to 1944 and were dropped at all seasons of the year. They were sired by 28 bulls, 15 of which had 3 or more calves. One hundred twelve dams were used.

Management of Cattle

Calves were weighed within 24 hours after birth. From approximately April 15 to November 15 each year cows and calves were run on improved pasture. While on pasture the cows received no supplemental feed. A concentrate mixture of 4 parts by weight of corn, 3 of oats, 2 of wheat bran, and 1 of linseed meal was placed in a creep once a day where the calves had access to it. During the remainder of the year the cows and calves were fed silage, mixed hay and small quantities of a grain mixture in dry lot. A creep for calves was also available.

In this study, data on growth and efficiency of gains are based on all calves fed out as steers. In the latter part of the experiment, and to some extent in the early part, each bull when two years old was mated to a group of about 20 cows selected at random within age groups to obtain, if possible, eight steer calves needed for his progeny test. The first eight male calves by each

[1]Bureau of Animal Industry, Washington 25, D. C., and Beltsville, Md.

sire were castrated at 140 days of age and fed out individually as a progeny test of the sire.

All except a few calves were weaned when they reached 500 pounds' weight, but for those few corrections have been made. The steer calves were individually fed and except for a somewhat higher proportion of corn in the early years of the work, they were given the following ration: 5 parts by weight of cracked shelled corn, 2 parts of crushed oats, 1 part wheat bran and 1 part linseed meal. They were fed all it was estimated they would clean up without going off feed. All the steer calves were fed to a slaughter weight of 900 pounds.

Methods of Study

In this study, the relation of the following factors to birth weight was determined: (1) age of the cow at the time the calf was born, (2) sex of the calf, (3) weight of the cow just after calving, (4) length of the gestation period, and (5) year of birth. Adjustments were made for these factors, where necessary, in certain phases of the determination of heritability of birth weight and the relation of birth weight to rate of growth and economy of gain.

Knapp, Lambert and Black (1940) found that birth weights of calves produced by any one cow tended to be less variable than those of calves from different dams. In order to equalize the effect of the dam in rating the sires and in calculating the percent to which birth weight was inherited, the birth weights of all calves from a given dam were averaged and this average figure (dam's index) used as a criterion of the dam's ability to influence birth weight.

As already stated, the studies on growth and efficiency of gain were confined to the calves fed out as steers. The inheritance studies involved all the calves from dams which produced at least one calf that was fed out as a steer.

Statistical procedures used in determining heritability of birth weight and relation of birth weight to subsequent performance are indicated in connection with presentation of the findings.

Results and Discussion

Factors affecting birth weight of calves

The average birth weight of the 402 calves was 70.5 pounds, for 212 male calves; the average was 72.2 pounds and for 190 females 68.7 pounds. The smallest calf weighed 40 pounds while the largest weighed 109 pounds at birth.

Birth weights tended to increase as the age of the dams increased until the dams were approximately six years old, after which there was no further

effect (figure 1). The regressions did not deviate significantly from linearity. Two hundred twelve males were on the average 0.23 pound heavier at birth and 190 females 0.20 pound heavier at birth for each increase of one month in the age of the dam to six years of age. Correlation coefficients between age of dam and birth weight of calves were 0.45 for male and 0.35 for female calves, considering all dams over six years as being six years old. Male calves averaged 4.2 pounds more than females when birth weights of all calves were corrected to the basis of having six-year old dams.

In 71 male calves that were later fed out as steers[2] the correlation between the age of the dams and the birth weights of the calves was 0.53** (the signifi-

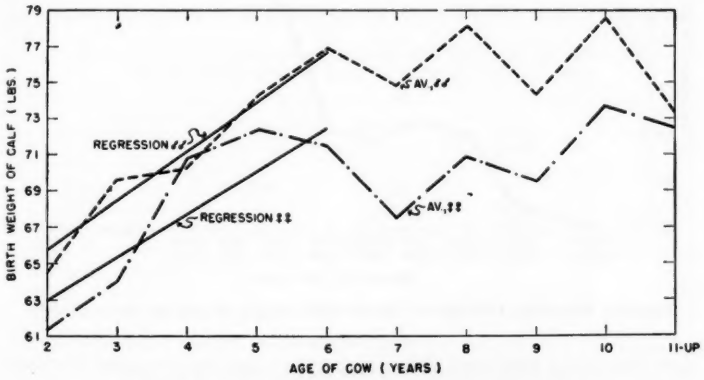

Figure 1. Relation of age of dam to birth weight of calf (212 male and 190 female calves).

cance of this and other correlations will be indicated by single asterisk for P = less than .05, and double asterisk for P = less than .01) and that between the weights of the dams just after calving and the birth weights of the calves was 0.49** (figure 2). The multiple correlation between the birth weights of these calves and the ages and weights of the dams was $R = 0.56^{**}$ or very little higher than the correlation with age alone.

For 64 of these 71 calves it was possible to figure the lengths of the gestation periods and to calculate the correlations between them and the birth weights of the calves. This correlation was found to be quite low $r = 0.25^{*}$. For all the calves (307) on which it was possible to get the length of the gestation period, the correlation was 0.32 with birth weight. For the 165 male calves it was 0.30** and for 142 females 0.32**. The average length of the

[2] 72 calves were fed out as steers but there were no weights for the dams of two of them. One steer calf, however, is included which was sold before completing the feeding period.

gestation period for the 307 calves was 281.2 days; that for 165 males was 281.6 days and for 142 females 280.7 days.

With respect to birth weights of 229 calves from sires which were used in two or more years, corrected for the age of the dam and sex of the calf,

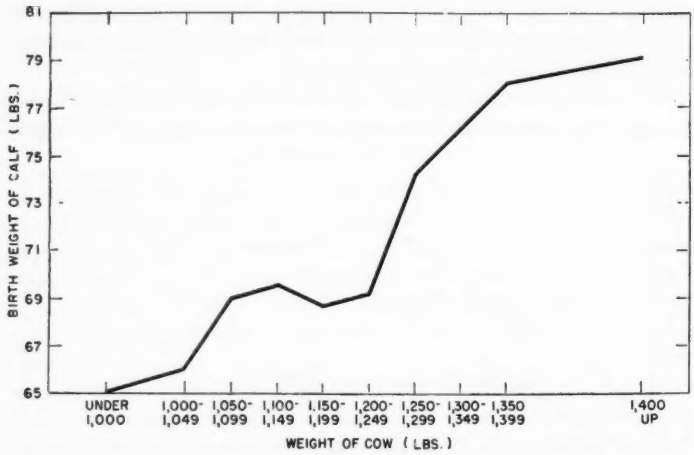

Figure 2. Relation of weight of dam to birth weight of calf (71 steer calves).

there was not a significant difference between the birth weights of calves born in different years to the same sires (table 1).

Heritability of birth weight

The inheritance of birth weight calculated from the paternal half sib correlation, with the use of the uncorrected birth weights of 227 calves, was 28.9 percent (table 2). The average age of the cows used in producing the steer calves was not the same for all sires to which these cows were mated,

TABLE 1. ANALYSIS OF VARIANCE BETWEEN YEARS WITHIN SIRES FOR BIRTH WEIGHTS OF CALVES[1]

Source of variance	Degrees of freedom	Sum of squares	Mean squares	F
Within sires	215	12,030.82		
Between years within sires	36	1,759.91	48.89	.85
Within years within sires	179	10,270.91	57.38	

[1] 229 calves from 14 sires used in two or more years. Birth weights were adjusted for age of dam and sex of calf.

but varied from 27.0 months to 63.3 months for the 13 sires with 3 or more calves.[3] Furthermore, the percentage of male calves was not equal for the different sires but varied from 53 to 75 percent. Therefore, actual birth weights of the male and female calves were corrected to the expected birth weights of calves from six-year-old dams on the basis of the regression coefficients, and the weights of the female calves were adjusted to the male level on the basis of the average difference between them when the dams were six years old. It was also found that the average birth weights of all calves from the cows used to produce the steer calves were not the same for all sires but varied from 71.9 pounds to 83.6 pounds after corrections had been made for the age of the dam and the sex of the calf. Thus the sires were not mated to cows of equal potentiality so far as the birth weights of their calves were

TABLE 2. ANALYSIS OF VARIANCE BETWEEN SIRES FOR THE UNADJUSTED BIRTH WEIGHTS OF THEIR CALVES[1]

Source of variance	Degrees of freedom	Sum of squares	Mean squares	F
Total	226	16,397		
Between sires	12	1,827	152.25	2.24[2]
Within sires	214	14,570	68.08	

[1] Includes only sires with three or more calves.
[2] Significant, $P = <0.05$.

concerned. When this difference in the dams was corrected for by covariance analysis and by using birth weights that had been adjusted for the age of the dam and the sex of the calf, the heritability of birth weight was found to be 11 percent (table 3). The differences between the sires, when the original birth weights were used, were significant. However, when the adjusted birth weights were used and corrections were made for differences in the dams, differences in the sires were not significant.

Even though the differences between the sires were not large enough with the number of sires tested (13) to be statistically significant, some differences were present. By comparing the average birth weight of a sire's calves with the average birth weight of all the calves from the cows to which he was mated, it was possible to tell which bulls were raising the average and which were lowering it. When this was done for the calves fed out as steers it was found, for example, that the steer calves from bull No. 149 averaged 4.4 pounds heavier than all the calves produced by their dams, while those from bull No. 123 averaged 1.7 pounds lighter than all the calves from their dams.

[3] Two of the 15 sires with 3 or more calves did not have a calf fed as a steer.

Relation of birth weight to rate of growth and economy of gain

There was considerable tendency among the 72 calves fed out as steers for the heaviest ones at birth to reach the weaning weight of 500 pounds before the lighter calves. The correlation coefficient between birth weight and the number of days required to reach 500 pounds was -0.58^{**}. There was much less tendency for the birth weight of these calves to be associated with the time required to grow from 500 pounds' weight to a slaughter weight 900 pounds in the feed lot (figure 3), the correlation being $+0.28^{*}$. However when the total time required for the calves to develop from birth to 900

TABLE 3. ANALYSIS OF VARIANCE AND COVARIANCE BETWEEN SIRES FOR ADJUSTED BIRTH WEIGHTS AND THE AVERAGE BIRTH WEIGHTS OF ALL THE CALVES BY A GIVEN DAM

Source of variance	Degrees of freedom	Sums of squares and products[1]			Errors of estimate		
		Sx^2	Sxy	Sy^2	Sum of squares	Degrees of freedom	Mean square
Total	226	13,112.81	4177.46	4224.74	2893.89	225	
Between sires	12	1,166.12	544.62	444.30			
Within sires	214	11,946.69	3632.84	3780.44	2675.74	213	12.56
Difference for testing adjusted sire means					218.15	12	18.18[2]

[1] x=adjusted birth weight; y=average birth weight of all calves by a given dam.
[2] F=1.45, not significant.

pounds was correlated with their birth weights, the coefficient was found to be -0.62^{*}, or approximately the same as that between birth weight and time to weaning. Figure 3 shows this relation in graphic form.

It was thought that the rate at which the calf developed before birth might be a better indication of the ability of the calf to grow than the birth weight. For 64 of the 72 calves fed out as steers the length of the gestation period was known. By dividing the birth weight by the length of the gestation period an average measure of the rate of growth before birth was obtained. This was termed the "prenatal rate of growth." When this was correlated with the time required by the calf to develop from birth to 500 pounds, from 500 to 900 pounds and from birth to 900 pounds, it was found that the correlation coefficients were -0.55^{**}, -0.16 and -0.54^{**}, respectively. The prenatal rate of growth as thus measured was, therefore, slightly less efficient as a measure of the growth expectation of the calf from birth to slaughter than the weight at birth.

Neither the birth weight nor the prenatal rate of growth of the steer

calves was found to be associated with their efficiency of gain (pounds of gain per 100 pounds of total digestible nutrients consumed) for the feeding period from weaning to slaughter. The correlation coefficients were 0.07 and −0.03, respectively, for birth weight and prenatal rate of growth with efficiency of gain. The partial correlation between birth weight and efficiency of gain, holding constant the number of days required from weaning to slaughter, was low, being −0.25.

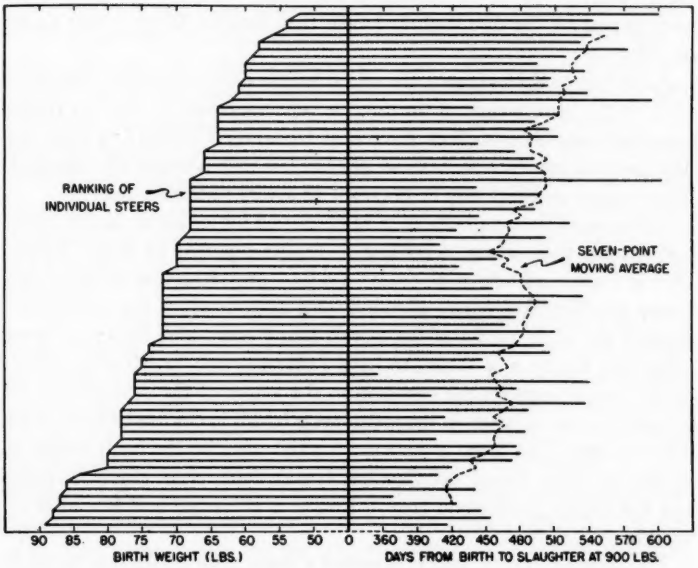
RANKING OF INDIVIDUAL STEERS
SEVEN-POINT MOVING AVERAGE
90 85 80 75 70 65 60 55 50
BIRTH WEIGHT (LBS.)
0 360 390 420 450 480 510 540 570 600
DAYS FROM BIRTH TO SLAUGHTER AT 900 LBS.

Figure 3. Association between birth weight and number of days required to grow from birth to a slaughter weight of 900 pounds (72 steer calves). Each line represents one steer. Steers are placed from top to bottom in order of weight at birth.

Discussion and Application of Results

The results in this study agree fairly well with most of those in the literature. The effect of age of dam on birth weight of the calf was similar to that found by Eckles (1919), McCandlish (1922), Fitch *et al.* (1924), and Knapp *et al.* (1940). Eckles (1919), McCandlish (1922), and Krasnov and Pak (1937) found positive associations between weight of dam and birth weight of calf. All investigators (Eckles, 1919; McCandlish, 1922; Fitch *et al.*, 1924; Morrison, 1936; Littlewood, 1937; Knapp *et al.*, 1940; Rhoad *et al.*,

1945) have found male calves, on the average, to be heavier than females. McCandlish (1922) reported the length of the gestation period to have little association with birth weight, while Eckles (1919), Fitch *et al.* (1924) and Krasnov and Pak (1937) found a slight association, and Knapp *et al.* (1940) a marked association. Fitch *et al.* (1924), Knott (1932), Knoop and Hayden (1934), Düring (1937), and Knapp *et al.*, (1940) reported that male calves were carried by the dam slightly longer than females. Wing (1899) found no difference.

According to Eckles (1919), the ration fed the dam appeared to have little effect on the birth weight of the calf. He believes, however, that in extreme cases there would be an effect. Fitch *et al.* (1924) reported the feed given the dam has some influence on birth weight but less than is commonly supposed. They suggest an effect may be obtained on a very restricted diet.

Calves sired by some bulls seem to be carried for longer or shorter gestation periods than others, according to results reported by Knott (1932), Düring (1937) and Rife *et al.* (1943). Eckles (1919), Rhoad *et al.* (1945) and Knapp and Nordskog (1946) all found some cases in which the sires had influenced the birth weight of the calves. Many cows were found by Wing (1899) and Knapp *et al.* (1940) to have a characteristic length of gestation. Snyder (1938) suggests the variation in the length of the gestation period is related to the variation in the sexual cycle which varies five or six days for different cows. The breed often has a marked effect on the birth weight as shown by Eckles (1919), McCandlish (1922), Fitch *et al.* (1924), Krasnov and Pak (1937), Littlewood (1937), Knapp *et al.* (1940) and Rhoad *et al.* (1945).

The Arizona Station (1937) reported a fairly high correlation (0.537 ± 0.031) between birth weight of range calves and their average daily gain to weaning. Krasnov and Pak (1937) found that the correlation between birth weight and weight at four months of age ranged from 0.39 to 0.58 for males and 0.43 to 0.48 for females. They also report a correlation between birth weight and adult weight of 0.56 for males and 0.41 for females.

The heritability of birth weight obtained in the present study from the unadjusted weights of the calves agreed fairly well with the figures of Knapp and Nordskog (1946), who report a heritability of 23 percent based on use of the paternal half-sib correlation method, and 34 percent from regression of progeny average on sire within year of sire. Their method of selecting cows for breeding was similar to the one used in this study but they do not report on its success. Even if comparable heterogeneous groups of cows are assigned to each bull, it does not follow necessarily that the distribution of the sex of the calves and the numbers of cows producing calves will be the same in all groups. This is a matter of considerable importance when a het-

erogeneous group of 20 cows is bred to a bull with the expectation of getting eight steer calves for a progeny test.

There are a number of factors which were not controlled in this study. These include yearly and seasonal differences; condition and nutrition of the cow during pregnancy, particularly the latter part of pregnancy; effect of pasture versus dry lot during the period from birth to weaning of the calf; effect of grain ration, consisting mostly of corn, versus a mixed grain ration in the feed lot; effect of certain steers being temporarily off feed at some time during the feeding period; and effect of differences in type and conformation of the animals. Possibly some other factors were only partially controlled. For instance, the calf-growing capacity of the reproductive tract of the dam was only partly measured by her age and weight. Also, the effect of the length of the gestation period may not have been entirely controlled by the use of the average birth weight of all a given dam's calves although it undoubtedly was partly allowed for in this way. With the present data it was possible to provide only those controls which were believed to be most important.

There is some evidence that the length of the gestation period may be inherited. Rife *et al.* (1943) and Livesay and Bee (1945) have shown that there are significant differences in average length of the gestation period between some breeds of cattle. It may be that inherited differences in the length of gestation, in the capacity of the reproductive tract, and in other purely maternal influences are generally more important in determining the birth weight of a calf within a breed than differences in growth rates transmitted from either parent. The effect of a bull on birth weight, when bred to cows of his own breed, might, therefore, be manifest more in his daughters' offspring than in his own. When crosses are made between breeds, however, the sire often has a marked effect on the birth weight of the calf (Rhoad, Phillips and Dawson, 1945). In finally determining the extent to which birth weight is inherited these things should be taken into account.

The fact that in this study the effect of birth weight was still evident even up to the time of slaughter at 900 pounds indicates the importance of considering those factors which influence it both in practical production and in the selection of breeding stock. In sheep, Phillips and Dawson (1940) found that the differences in birth weight were marked at three months of age but tended to disappear by the time the sheep were a year old. It may be that a similar situation would be found in cattle if carried to an older age. The trend, however, to market cattle at younger, rather than older ages, will increase the importance of birth weight rather than diminish it.

The relative value of birth weight as an indicator of subsequent growth may be illustrated by a comparison of certain correlations between early

measures and subsequent growth, as follows:

Correlation between:	*Coefficient of correlation*
Birth weight, and days from 500 to 900 lbs.	−0.28
Days from birth to 500 lbs., and days from 500 to 900 lbs.	−0.04
Birth weight, and days from birth to 900 lbs.	−0.62

Thus, birth weight is a better indicator of growth after weaning than is rate of growth to weaning at 500 lbs. The latter measure would obviously be affected materially by the dam's milking capacity. Birth weight has an even higher relationship with days from birth to 900 pounds.

It is not supposed that one would wish to breed indiscriminately for extremely large calves. The correlations obtained in this study with the use of prenatal rate of growth, indicate that it might be advantageous to select calves which are relatively large but from average or slightly less than average gestation periods. This would tend to avoid some of the difficulties that might be encountered if breeders obtained extremely large calves for the size of the dam and longer than average gestation periods.

Summary

Birth weights of calves in the beef Shorthorn herd at Beltsville, Maryland tended to increase at the rate of 0.2 pound per month of increase in the age of the dam until the dams were six years old, after which there was no effect of age of dam.

When birth weights were adjusted to the basis of six-year old dams, male calves averaged 4.2 pounds heavier than females.

Weight of dam was found to be related to birth weight of calf to about the same extent as was the age of the dam.

The multiple correlation between both age and weight of dam and birth weight was 0.56, or very little higher than the simple correlations.

A significant but relatively low positive correlation was found between the length of the gestation period and birth weight.

With the use of half-sib correlations, heritability of the original birth weight was 29 percent, while for birth weights corrected for age of cow, sex, and dam's index (average birth weight of all calves from a given dam) the heritability was 11 percent.

Of the calves which were fed out as steers, the largest ones at birth and those with the highest prenatal growth rates tended to reach 500 pounds (weaning weight) and 900 pounds (slaughter weight) the soonest. There was little relationship between birth weight or prenatal growth rate and the length of the feeding period from weaning to slaughter. Correlations between birth weight or prenatal growth rate and economy of gain during

the feeding period showed there was practically no association.

The results of this study indicate that birth weight should be given some consideration in selection, in view of the fact that it had an influence on the time required for the animals to attain a slaughter weight of 900 pounds. The results also indicate that since the dam had a considerable maternal influence on birth weight as well as on the subsequent development of the calf, greater care should be taken in the selection of the dams and in the evaluation of their influence in progeny tests of sires.

Literature Cited

Arizona Agricultural Experiment Station. 1937. Heavy Calves Make Rapid Gains. Ariz. Agr. Expt. Sta. Ann. Rept., 48: 35–36.

Düring, T. 1937. Do the Spermatozoa Influence the Duration of Pregnancy in Cattle? Zeitschrift für Zuchtung, B, 39: 26–30.

Eckles, C. H. 1919. A Study of the Birth Weight of Calves. Missouri Agr. Expt. Sta. Res. Bul. 35.

Fitch, J. B., P. C. McGilliard and G. M. Drumm. 1924. A Study of the Birth Weight and Gestation of Dairy Animals. Jour. Dairy Sci., 7: 222–233.

Knapp, Bradford, Jr., W. V. Lambert and W. H. Black. 1940. Factors Influencing Length of Gestation and Birth Weight in Cattle. Jour. Agr. Res. 61: 277–285.

Knapp, Bradford, Jr. and Arne W. Nordskog. 1946. Heritability of Growth and Efficiency in Beef Cattle. JOURNAL OF ANIMAL SCIENCE, 5: 62–70.

Knoop, C. E. and C. C. Hayden. 1934. A Study of the Length of Gestation and Service Record of Dairy Cows. Ohio Agr. Expt. Sta. Bimo. Bul. 166: 8–14.

Knott, J. C. 1932. A Study of the Gestation Period of Holstein Friesian Cows. Jour. Dairy Sci., 15: 87–98.

Krasnov, K. E. and D. N. Pak. 1937. Opyt ocenki tagiljskih bykov po živomu vesu potomstva pri roždenii. (An attempt at testing Tagil bulls by the birth weight of their progeny.) Usp. zooteh. Nauk, 4(1): 31–45. (English Summary). (Abstracted Anim. Breeding Abstracts, 7: 108, 1939.)

Littlewood, R. W. 1937. Weight of Calves and Period of Gestation in Some Indian Breeds of Cattle. Agriculture and Live-Stock in India, 7: 61–64.

Livesay, E. A. and Ural G. Bee. 1945. A Study of the Gestation Periods of Five Breeds of Cattle. JOURNAL OF ANIMAL SCIENCE, 4: 13–14.

McCandlish, Andrew C. 1922. Studies in the Growth and Nutrition of Dairy Calves. Jour. of Dairy Sci. 5: 301–320.

Morrison, F. B. 1936. Feeds and Feeding. The Morrison Publishing Co., Ithaca, New York, p. 615.

Phillips, Ralph W. and W. M. Dawson. 1940. Some Factors Affecting Survival, Growth and Selection of Lambs. U. S. Dept. Agr. Cir. 538.

Rhoad, Albert O., Ralph W. Phillips and Walker M. Dawson. 1945. Evaluation of Species Crosses of Cattle by Polyallel Crossing. Jour. Hered. 36: 367–374.

Rife, David C., Paul Gerlaugh, Lawrence Kunkle, Graydon W. Brandt and Laurence H. Snyder. 1943. Comparative Lengths of the Gestation Periods of Aberdeen-Angus and Hereford Cows Carrying Purebred and Crossbred Calves. JOURNAL OF ANIMAL SCIENCE, 2: 50–52.

Snyder, Franklin F. 1938. Factors Concerned in the Duration of Pregnancy. Physiol. Rev. 18: 578–596.

Wing, Henry H. 1899. The Period of Gestation in Cows. N. Y. (Cornell) Agr. Expt. Sta. Bul. 162: 323–334.

APPLICATION OF WATER TO THE BODY SURFACE OF WATER BUFFALOES AND ITS EFFECT ON MILK YIELD

K. C. SINHA AND F. C. MINETT[1]

Imperial Veterinary Research Institute[2]

IT IS well-known that adequate heat dissipation is essential for the maintenance of a normal body temperature and for normal functioning of the organs. In cattle generally, heat dissipation begins to be difficult when air temperatures reach the 70–80° F. level. In conformity with this, water buffaloes, unlike most other domesticated animals, have developed the habit of bathing or wallowing. It has therefore become a practice to cool buffaloes, by permitting them to wallow once or twice daily in a tank or to splash their bodies with water from buckets. The effects of these practices on body temperatures have been reported in an earlier paper (Minett, 1947). This practice is said to be particularly necessary with females, but no exact enquiry to measure the effect of this splashing on the milk yield has been reported. To obtain some information on this matter, observations were made in the months of May and June, 1945, at the Military Farm, Bareilly, United Provinces. Since atmospheric and other conditions were more or less the same during this period, any abrupt deviations in milk yield may be more readily ascribed to the conditions imposed, viz., splashing or non-splashing.

Material and Experimental Methods

The procedure was to make four sets of observations over consecutive periods of 10 days each. In the first period, the normal routine of splashing was followed, except for certain minor alterations mentioned below as necessary to make the conditions more exact. In the second period splashing was omitted. In the third period the original group of animals was divided into two subgroups, one of which was given daily splashing and the other not, while in the fourth period all animals were brought back to the routine practice of splashing. For the experiment, 22 buffaloes, 8–10 years old, were selected, so as to obtain a group of animals as near as possible to their maximal yield, which is usually at about 90 days after calving. The average duration of lactation for the experimental group thus formed was at the outset 86.9 days. Unfortunately, for reasons stated below the records of all 22 animals could not be utilized.

[1] The authors are grateful to Col. G. E. Macguckin, Director of Military Farms, and to Mr. Har Swaroop Narad the Farm Manager at Bareilly for arranging facilities for this work. The statistical work was carried out by Mr. Suprakas Sen.

[2] Izatnagar, U. P., India.

No alteration was made in the animal's daily ration or routine during the four periods. They remained in open paddocks from 3:00 to 7:00 A.M. and 5:00 to 7:00 P.M., during which time they were allowed to drink at will, and at other times they were stalled. When splashing was carried out, this was done two hours before milking times, which were 11:00 A.M. and 11:00 P.M. Milk was weighed on a spring balance, records being taken in the presence of one author to the nearest two ounces. Air temperature and humidity figures were obtained from a meteorological station two miles from the farm.

TABLE 1. ENVIRONMENTAL CONDITIONS AND MEAN DAILY MILK YIELDS OF WATER BUFFALOES IN PERIODS I AND II

Date	Air temp. degrees F.		Relative humidity, percent		Rainfall, inches	Temp. of splash water, degrees F.		Body temp. variation, degrees F.*		Avg. milk yield, lbs.	
	Max.	Min.	A.M.	P.M.		A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
Period I											
May 1	103	71	40	13	0	80	82	−0.6	−0.4	6.78	6.77
2	105	77	43	13	0	81	84	−0.7	−0.7	6.87	6.95
3	106	73	24	5	0	83	85	−0.9	−0.7	6.68	6.95
4	106	75	24	5	0	84	86	−0.8	−0.7	7.28	7.23
5	106	72	23	6	0	85	86	−0.9	−1.0	7.09	7.32
6	108	77	25	13	0	84	86	−0.7	−0.8	7.17	6.97
7	109	82	29	11	0	82	84	−0.8	−0.7	7.22	6.83
8	109	79	23	9	0	82	84	−0.8	−0.8	6.57	6.28
9	108	83	24	6	0	83	86	−1.0	−0.9	6.63	6.83
10	107	75	27	9	0	83	85	−1.0	−0.7	7.18	7.05
Period II											
May 11	108	76	26	9	0			+0.1	−0.1	6.45	6.64
12	107	78	23	9	0			0.0	−0.1	6.58	6.21
13	108	78	24	13	0			0.0	−0.2	6.47	6.98
14	108	80	25	7	0			0.0	−0.2	6.32	6.70
15	108	78	41	21	0			−0.1	−0.1	6.62	6.30
16	101	79	46	27	0			+0.1	0.0	6.42	6.99
17	100	81	42	29	0			−0.1	−0.3	6.67	6.67
18	101	75	53	39	0			+0.1	−0.1	6.55	6.62
19	97	73	73	33	0.2			+0.1	−0.1	6.93	6.70
20	99	77	59	27	0			0.0	−0.2	6.64	6.53

* Minus sign indicates fall in temp., and plus sign indicates an increase.

During the first period all the buffaloes were splashed much as usual, viz., for 5 minutes morning and evening (between 9:00 and 10:45) by throwing water over their bodies with buckets. Body temperatures were

TABLE 2. ENVIRONMENTAL CONDITIONS AND MEAN DAILY MILK YIELDS OF WATER BUFFALOES IN PERIOD III

Environmental Conditions

Date	Air temp. degrees F.		Relative humidity, percent		Rainfall, inches	Temp. of splash water, degrees F.*	
	Max.	Min.	A.M.	P.M.		A.M.	P.M.
May 21	103	78	47	28	0	81	84
22	105	81	29	17	0	82	83
23	106	83	38	7	0	80	81
25	108	74	16	11	0	82	84
26	111	84	23	17	0	83	84
27	109	85	23	8	0	82	84
28	110	82	45	16	0	80	82
29	106	78	42	26	0	82	83
30	102	82	59	18	0	81	82
31	104	76	45	23	0	82	84

Body Temperature Changes and Milk Yields

Date	Subgroup I (splashed)				Subgroup II (not splashed)			
	Body temp. variation, degrees F.		Avg. milk yield, lbs.		Body temp. variation, degrees F.		Avg. milk yield, lbs.	
	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
May 21	−0.8	−0.7	6.95	7.00	0.0	−0.1	5.95	6.50
22	−0.6	−0.7	7.07	7.07	−0.2	+0.1	6.11	6.64
23	−0.8	−0.8	7.07	7.00	0.0	−0.1	6.14	6.54
25	−0.4	−0.9	7.32	7.07	+0.1	−0.2	6.66	6.79
26	−0.5	−0.7	7.61	7.00	+0.1	−0.1	6.46	6.57
27	−0.5	−0.7	7.32	7.57	0.0	−0.1	6.71	6.64
28	−0.5	−0.7	7.50	7.57	+0.2	−0.1	6.50	6.50
29	−0.8	−0.5	7.50	7.43	+0.3	0.0	6.36	6.00
30	−0.7	−0.9	7.46	7.50	0.0	0.0	6.50	6.57
31	−0.7	−0.8	6.36	7.50	−0.1	−0.2	6.11	6.71

* Minus sign indicates fall in temp., and plus sign indicates increase rise.

recorded immediately before and one-half hour after splashing. The only deviation from the normal routine was that the duration of splashing was exactly 5 minutes and care was taken to wet their bodies thoroughly, even beneath the abdomen.

During the second period body wetting was omitted. Body temperatures, however, were taken twice daily at about the same times as during the first period, three recordings being made on each occasion at half-hour intervals.

During the third period the 22 animals were divided into two subgroups

of 11 each. Those in subgroup I were splashed for 5 minutes morning and evening, while animals of subgroup II were not splashed. Body temperatures of the first subgroup were recorded before and half-an-hour after splashing, in subgroup II three temperature recordings were taken at about the same times at half-hour intervals.

During the fourth period, all animals were splashed as usual. Unfortunately, the weather conditions at this period differed somewhat in that

TABLE 3. ENVIRONMENTAL CONDITIONS AND MEAN DAILY MILK YIELDS OF WATER BUFFALOES IN PERIOD IV

Date	Air temp., degrees F.		Relative humidity, percent		Rainfall, inches	Temp. of splash water, degrees F.		Body temp. variation, degrees F.*		Avg. milk yield, lbs.	
	Max.	Min.	A.M.	P.M.		A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
June 1	103	83	35	16	0	83	85	−0.6	−0.8	6.61	6.50
2	106	81	36	17	0	82	83	−0.8	−0.8	6.37	6.60
3	108	84	26	13	0	82	84	−0.6	−0.8	6.52	6.43
4	109	81	27	13	0	80	82	−0.7	−0.7	6.22	6.50
5	111	89	22	10	0	82	84	−0.8	−0.7	6.27	6.53
6	113	90	33	15	0	83	84	−0.8	−0.7	6.72	6.38
7	112	86	60	18	0	82	86	−0.7	−0.7	6.45	6.77
8	108	84	49	18	0	83	82	−0.7	−0.7	6.40	6.63
9	110	81	51	7	0	83	86	−0.8	−0.7	6.27	6.27
10	112	81	39	12	0	84	86	−0.7	−0.6	6.18	6.63

* Minus sign indicates fall in temp., and plus sign indicates increase rise.

air temperatures were higher than before, and the hot spring wind, known as the loo, and characteristic of the plains of North India, had begun.

Results

The mean daily milk yields of 15 animals are shown in tables 1 and 3. A larger number would have been used had it not been for some gross irregularity in yield, due to temporary sickness such as tympanites, rendering certain animals unsuitable for experiment. The average duration of lactation of the group at the beginning of the four periods was as follows: Period I—86.6 days; period II—96.6 days; period III, subgroup I—105.6, and subgroup II—106.2 days; period IV—116.6 days. During the third period, 14 were used viz., 13 of the 15 used in period I, and one other. As stated, these 14 animals were divided into two subgroups, their average duration of lactation at this time being 105.6 and 106.2 days, respectively. The mean daily milk yields of these two subgroups in period III and of the *same* animals during the other three periods are shown in figure 1, which also shows the mean

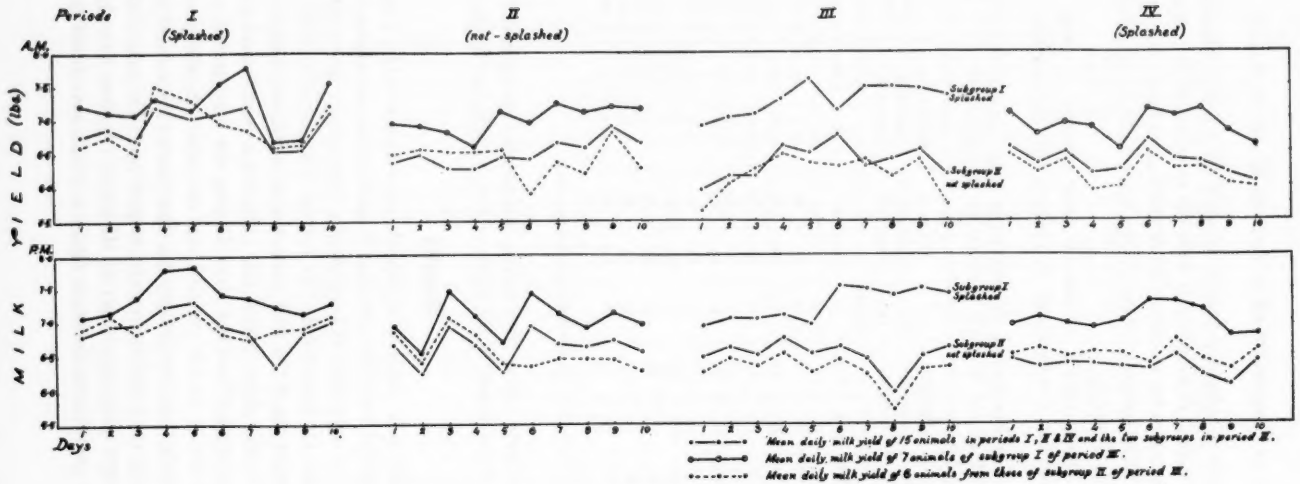

Figure 1. Mean daily milk yields during splashing and non-splashing periods.

TABLE 4. DIFFERENCES IN MEAN MILK YIELDS OF SPLASHED AND UNSPLASHED WATER BUFFALOES

Comparison	Groups Compared			No. of animals[1]	Milk yield		Significance of difference**
	Time	Period	Treatment		Mean for 10-day period, lb.	Difference, lbs.	
1	A.M.	I	Splashed	15	6.95±0.063*		
		II	Not splashed	15	6.56±0.039	0.39±0.074*	h.s.
2	P.M.	I	Splashed	15	7.92±0.054		
		II	Not splashed	15	6.63±0.039	0.29±0.075	h.s.
3	A.M.	III	Subgroup I, splashed	7	7.32±0.051		
		II	Not splashed	7	7.04±0.065	0.28±0.083	h.s.
4	P.M.	III	Subgroup I, splashed	7	7.27±0.053		
		II	Not splashed	7	7.02±0.086	0.25±0.101	s.
5	A.M.	III	Subgroup I, splashed	7	7.32±0.051		
		IV	Splashed	7	6.94±0.157	0.38±0.165	s.
6	P.M.	III	Subgroup I, splashed	7	7.27±0.053		
		IV	Splashed	7	7.03±0.051	0.24±0.074	h.s.
7	A.M.	IV	Splashed	6	6.21±0.098		
		III	Subgroup II, not splashed	6	6.13±0.104	0.08±0.143	n.s.
8	P.M.	IV	Splashed	6	6.39±0.067		
		III	Subgroup II, not splashed	6	6.29±0.080	0.10±0.104	n.s.

[1] In each comparison, the same animals were used in the two periods for which data are compared.
* Standard error.
** h.s. = highly significant.
s. = significant.
n.s. = not significant.

milk yields of the 15 animals originally selected. Statistical analyses are set out in table 4.

Behaviour of Animals in Different Periods

During the first period the extent of body cooling by splashing was 0.73° F. in half-an-hour as against 0.06° F. in one hour without splashing during the second period (table 1). The experimental animals in the latter half of the second period were perhaps in rather more favorable environmental conditions, as the air temperature fell a little, though this was offset by a rise in relative humidity. From table 1. however, it is seen that the daily

mean milk yields during the second period dropped significantly, that is during the time when the animals were not being splashed; further, the level of milk became irregular, this being more marked with the evening yield (figure 1). From comparisons 1, 2, 3 and 4 (table 4), it is seen that the milk yield level declined significantly when the animals were not splashed.

The extent of body cooling induced by splashing during the third period was 0.68° F. in half-an-hour (subgroup I), whereas it was 0.02° F. in one hour without splashing in subgroup II (table 2). During this period the mean daily milk yield of the splashed animals showed a tendency to rise, a trend not observed in the unsplashed animals (table 2). The evening milk yield of the unsplashed animals was also irregular during this period (figure 1).

During the fourth period the buffaloes showed a decline in yield. But the level during this period of extreme air temperature, when the animals were more advanced in lactation, is not unlike that of the second period when the air temperature was lower and the buffaloes were nearer the peak of their lactation (figure 1). Also, the irregularity seen during the periods of non-splashing was not marked during period IV.

Summary

Observations were carried out on 15 milking buffaloes during the optimal period of their lactation, in order to ascertain whether any relationship exists between milk yield and cooling of the body by daily wetting of the body surface.

It has been shown that during the hot months body wetting is essential. When this is not practiced as a routine, the milk yield decreases and also becomes more irregular. Such differences are found to be statistically significant.

Literature Cited

Minett, F. C. 1947. Effects of Artificial Showers, Natural Rain and Wallowing on the Body Temperatures of Animals. JOURNAL OF ANIMAL SCIENCE, 6: 35–49.

EFFECTIVENESS OF SELECTION FOR EFFICIENCY OF GAIN IN DUROC SWINE

G. E. Dickerson and J. C. Grimes[1]

United States Department of Agriculture and Alabama Agricultural Experiment Station

Introduction

IT IS generally recognized that feed costs comprise about two-thirds of the total costs of the swine enterprise and more than three-fourths of the cost of rearing pigs from weaning to market weight. In attempting to reduce the post-weaning feed costs in pork production through breeding, breeders have selected for rapid gains rather than directly for low feed requirements per unit of gain. Rate of gain is more easily measured than feed consumption and the two have been fairly closely correlated in studies of swine data (e.g. $r = -.7$ approximately; Evvard *et al.*, 1927; and Lush, 1936). Just how effective selection for rapid gains is in reducing inherent feed requirements per unit of gain depends on (1) how much of the observed differences in gain are heritable and on (2) the extent to which heritable differences in rate of gain and feed requirements are caused by the same genetic factors. The effectiveness of selecting directly for low feed requirements depends on the heritability of differences in feed requirements. Estimates are available in the literature for heritability of rate of gain but not for heritability of feed utilization or for the genetic correlation between these traits, largely because individual feed records have been obtained only rarely. Lush (1936) has presented some evidence on the relative heritability of rate and economy of gain based on litter averages.

Controlled experiments measuring the cumulative effects of selection have been reported for oil content of corn by Winter (1929) and "Student" (1934), for egg production in poultry by Marble and Hall (1931), for body size in mice by MacArthur (1944), for food utilization in rats by Morris *et al.* (1933), and for growth rate in swine by Krider *et al.* (1946). The present paper reports the results of selecting individual pigs for low feed requirements in one line and for high feed requirements in another line of Duroc swine over a period of 8 years at the Alabama Agricultural Experiment Station. The data also permit estimates of heritability and of genetic correlation between traits, based on correlations between related animals.

[1] The data studied were collected in a selection experiment at the Alabama Agricultural Experiment Station under the direction of the junior author. Through the courtesy of Professor Grimes the data were made available to the Department's Regional Swine Breeding Laboratory for analysis. The senior author completed the analysis and prepared the manuscript with the cooperation of the junior author.

Experimental Procedure

The foundation stock consisted of 15 unrelated boar and gilt pairs, representing a considerable range in type. They were purchased in 1936 from well known Duroc herds throughout the United States. Each of the 15 gilts was mated to a different and unrelated boar. All pigs in the 8 largest and heaviest litters weaned from these matings in the spring of 1937 were used as the foundation stock for the selection experiment. These and later generations of pigs were full-fed a single mixed ration from 72 days of age to a live weight of 225 pounds in individual 6′×18′ pens with concrete floors. The boar and the gilt pig making the most economical gains in each of the 8 litters were selected as parents for litters of the Superior line in 1938. Similarly, the boar and gilt making the least economical gains in each of the same 8 litters were chosen as parents for litters of the Inferior line in 1938. Until 1942, an attempt was made to save the most economical boar and gilt from each of 8 Superior line litters, and the least economical pair from each of 8 Inferior line litters, as parents of the next generation in each line. Except for four litters in 1940 from 2-year-old sires or dams, each litter was from a different young boar and gilt. Relationship between mates was in most instances kept at a minimum in order to avoid inbreeding. All pigs were fed individually until 1942. Beginning in 1942, a few older sires, which had been used in previous years, sired most of the litters, and part of the litters were from older sows. In 1942, 1943, and 1944 many of the pigs were fed in groups of litter mates, divided on the basis of sex unless the boars were castrated. All pigs were fed individually again in 1945. All litters tested included every living pig in the litter. Unavailability of certain ingredients required some modification of the protein and mineral supplement in the ration in 1943 through 1945. During 1942 to 1945, an increasing proportion of the litters tested were descended from 1937 Superior line foundation animals through two rather highly inbred families that had not been tested during the intervening years. Also, the number of litters in the Inferior line began to decline in 1941 because of an increasing number of the litters having no pigs sufficiently mature to breed for spring litters. Thus, much of the data after 1941 did not add to the information on cumulative effects of selection, although it was usable in obtaining correlations between relatives.

Results

Data from this experiment provided three kinds of evidence concerning heritability of economy and rate of gain and the genetic correlation between the two: (1) cumulative effects of selection on the difference between lines, (2) regression of progeny on the parents, and (3) analysis of variance and covariance for sire, litter, and intralitter differences.

Cumulative Effects of Selection

One boar and one gilt were usually selected from each litter on the basis of individual feed requirement per unit of gain from 72 days of age to a live weight of 225 pounds, regardless of the average feed requirement for the

TABLE 1. MEAN SUPERIORITY (+) OR INFERIORITY (−) OF SELECTED PARENTS, COMPARED WITH THE UNSELECTED PROGENY IN THE SAME LINE THE PRECEDING YEAR[1]

Item	Line	Parents of progeny in					Totals
		1938	1939	1940	1941	1942[2]	
Number of progeny	S	50	37	59	57	67	270
	I	62	44	50	45	22	223
	Total	112	81	109	102	89	493
Weight at birth, (pounds)	S	+ .12	− .14	− .04	− .09	+ .12	− .03
	I	− .09	− .03	− .12	− .34	+ .30	− .28
	Cum. S-I	+ .21	+ .10	+ .18	+ .43	+ .25	
Weight at 72 days, (pounds)	S	+ .15	+ 2.40	− 2.03	+ 1.64	− 2.50	− .34
	I	+ 1.07	+ 4.22	− 1.05	+ 2.21	+ 1.88	+ 8.33
	Cum. S-I	− .92	− 2.74	− 3.72	− 4.29	− 8.67	
Feeding period, (days)	S	− 9.15	−12.12	+ 1.32	−10.52	+ 4.52	−25.95
	I	+ 6.34	− 9.71	+ 7.48	−10.50	+ 4.08	− 2.31
	Cum. S-I	−15.49	−17.90	−24.06	−24.08	−23.64	
Daily gain, (pounds)	S	+ .098	+ .094	+ .070	+ .104	− .063	+ .303
	I	− .068	+ .044	− .040	+ .077	− .066	+ .053
	Cum. S-I	+ .166	+ .216	+ .326	+ .353	+ .356	
$\frac{\text{Feed}}{\text{Gain}} \times 100$, (pounds)	S	−17.9	−18.3	− 2.7	−13.1	+ 9.0	−43.0
	I	+20.5	+ 9.1	+15.7	−12.4	+26.2	+59.1
	Cum. S-I	−38.4	−65.8	−84.2	−84.9	−102.1	

[1] Each parent's deviation was weighted according to its number of progeny in obtaining the mean for a line and year.

[2] In 1942, when the litters were all by sires older than one year, each sire's deviation from the line mean for its year of birth was adjusted to the equivalent deviation from the mean of the preceding year by subtracting the amount of selection during the intervening years.

litter. Thus, selection was largely between litter mates, no consideration being given to the differences due to the dam's direct influence and to the transmitted influence of the sire and dam. The amount of selection actually practiced each year is shown in table 1 by the average deviations of the parents from the mean of all pigs fed in that line the preceding year. The

amount of selection was similar among boars and gilts. During the five generations, the total amount of intra-year selection on feed per 100 pounds of gain was the equivalent of choosing parents that averaged 43 pounds below the common 1937 foundation stock for the 1942 Superior line pigs and parents that averaged 59 pounds above the 1937 foundation stock for the 1942 Inferior line pigs. This was a difference of 102 pounds between parents of 1942 pigs in the two lines. There was considerable indirect selection for faster gains after 72 days of age in the Superior line, amounting to selecting

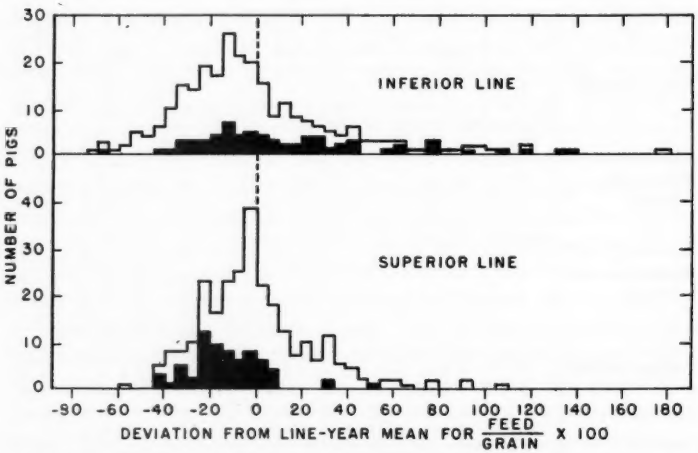

Figure 1. Frequency distribution of deviations from the mean of the line and year for all offspring (unshaded) and for those selected as parents (shaded) in each line during five generations.

parents of 1942 pigs averaging .30 pound higher in daily gain and 25 days shorter in feeding period than the 1937 foundation stock. However, the least economical boar or gilt in an Inferior line litter was often too small to breed for the next year's litters, and the next least economical pig that was big enough had to be substituted. As a result, selection for high feed requirement was lessened, there was no indirect selection for slower gains after 72 days of age, and parents actually were appreciably above average in 72-day weight. Indirect selection for birth weight was negligible in both lines. Figure 1 illustrates how far the actual selection on feed requirements fell short of the maximum that could have been practiced if the extreme individuals had been retained for breeding regardless of the litter from which they came and the age at which they would breed. Selection among boars also could have been more intense if fewer had been used.

TABLE 2. MEAN PERFORMANCE OF UNSELECTED PROGENY BY LINES AND YEARS[1]

Item	Line	Foundation 1937	Year 1938	1939	1940	1941	1942
No. of progeny	S		50	37	59	57	67
	I	67	62	44	50	45	22
Age of dams at farrowing, (months)	S	—	12.0	12.3	15.3	11.4	12.5
	I		12.4	12.1	12.5	11.3	11.7
Inbreeding of pigs, (percent)	S		0	0	0.7	5.1	6.9
	I	0	0	4.8	0	0.8	8.7
Number of pigs fed per litter	S		6.25	5.29	7.38	7.12	7.44
	I	8.38	7.75	5.50	6.25	7.50	7.33
Birth wt., (pounds)	S		2.66	2.76	2.59	2.56	2.55
	I	2.66	2.43	2.42	2.44	2.49	2.41
	S-I		.23	.34	.15	.07	.14
Weight at 72 days, (pounds)	S		44.66	31.32	42.41	40.16	30.58
	I	31.01	36.77	23.09	31.88	38.47	31.77
	S-I		7.89**	8.23*	10.53**	1.69	−1.19
Feeding period, (days)	S		124.7	139.8	121.2	138.1	142.3
	I	124.1	153.6	164.9	141.3	140.0	158.7
	S-I		−28.9**	−25.1*	−20.1*	−1.9	−16.4
Daily gain, (pounds)	S		1.492	1.409	1.544	1.378	1.399
	I	1.599	1.317	1.265	1.396	1.366	1.240
	S-I		.175*	.144	.148	.012	.159
$\frac{\text{Feed}}{\text{Gain}} \times 100$, (pounds)	S		387.7	368.0	340.5	365.3	351.7
	I	350.2	413.7	384.3	359.6	385.6	376.7
	S-I		−26.0*	−16.3	−19.1	−20.3	−25.0

* Indicates $P \leq .05$.

** Indicates $P \leq .01$.

[1] These means include only pigs whose ancestors were all tested individually for feed utilization, back to the 1937 foundation stock.

The mean performance of all pigs fed is shown in table 2 for the foundation stock and the first five generations of the two lines. The litters fed in 1943, 1944, and 1945 are omitted, because they were either from older sows, from untested ancestors, or from parents fed in lots of several litter mates,

which made it impossible to calculate the individual parent's deviation from the average of its generation. The mean difference in feed requirement between the Superior and Inferior lines (S-I in table 2) in each generation is an estimate of the genetic difference that has accumulated as a direct result of selection for opposite extremes in the two lines. This is illustrated in figure 2.

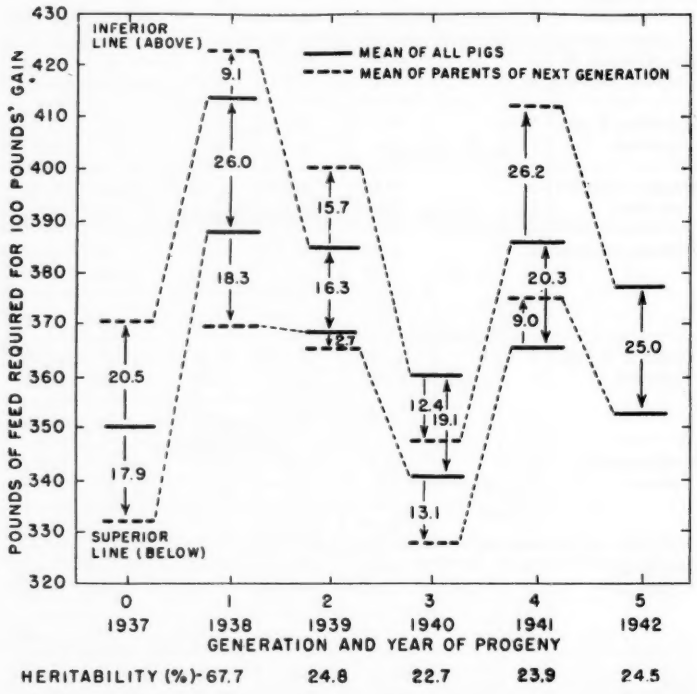

Figure 2. Mean feed requirement for 100 pounds of gain for all pigs and for parents of the next generation, in each generation of the Superior and Inferior lines, showing the effects of selection.

Estimates of the actual effectiveness of selection (among litter mates) are shown at the bottom of figure 2. They are based on the amount of selection towards opposite extremes and the resulting line differences. For example, Superior line pigs required 25.0 pounds less feed for 100 pounds of gain than Inferior line pigs in 1942 as a result of 5 generations of selection equivalent to an intra-litter difference of 102.1 pounds between parents of the 1942 pigs in the two lines (table 1). This indicates that selection was 24.5 percent ef-

fective. Corresponding estimates from the first four generations were 67.7, 24.8, 22.7, and 23.9 percent. The intra-year line difference in feed requirement was statistically significant in only the first generation. However, the average line difference during the four succeeding generations and, hence, the average estimate of heritability therefrom (24.0 percent) were highly significant ($P < .01$).

It seems likely that the actual heritability of intra-litter differences in feed requirements is closer to the 24 percent than to the average of 33 percent which includes results of the first generation of selection. First, the 4 estimates from generations after the first all fell within the range from 23 to 25 percent. Second, there are several reasons for considering the 68 per cent heritability from the first generation an overestimate. Parents were chosen from only the largest and thriftiest litters of the 15 litters farrowed in 1937. This partly accounts for the daily gain being larger and feed requirements lower in 1937 than in 1938 (1.6 vs. 1.5 and 1.3, and 350 vs. 388 and 414 pounds). The higher the average rate of gain, the smaller the change in length of feeding period (to the 225 pound weight) that will result from a given difference in rate of gain. For this reason, the frequency distribution of feed requirements is decidedly skewed (figure 1) and there was less variation in feed requirements between litter mates in 1937 than in later years (σ less by about one-fifth). Genetic variation among litter mates was presumably no less in 1937 than in later generations. Hence, a given difference in feed requirements of parents chosen from the selected litters of 1937 would result in a larger difference in their unselected progeny than would a similar difference between parents from the unselected litters in later years. The 8 litters in 1937 were selected partly for greater uniformity in weight at 72 days (σ less than in later years by about one-fifth), which also would tend to make differences in subsequent feed requirements more largely hereditary. Furthermore, there may be an optimum range in feed requirements beyond which selection for either extreme becomes less effective because of its effect on other vital functions. A tendency for inherently lower feed requirements to be associated with poorer milking ability (Dickerson, 1947) would have this effect.

No attempt is made to calculate heritability for the items indicative of growth rate from the line differences, because selection was based primarily on feed requirements. If selection were based entirely on feed requirements, the portion of the average superiority or inferiority of parents in rate of growth (table 1) that is heritable would depend on the relative sizes of the regressions of genotype (G_r) and of phenotype (R) for growth on phenotype (F) for feed requirements (i.e. on b_{G_rF}/b_{RF}). This involves the heritability of feed requirements as well as of growth rate, and also the genetic and the total correlations between feed requirements and rate of growth. Interpreta-

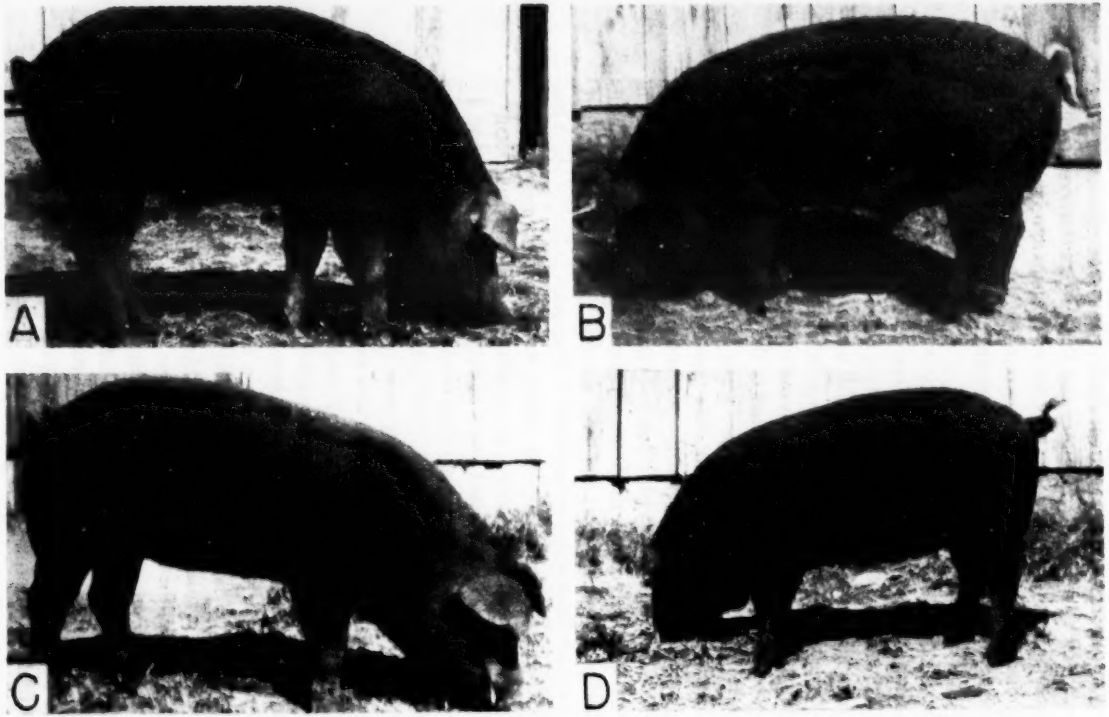

Figure 3. Representatives of the Inferior and Superior strains of Durocs at the 225 pound weight. A. Inferior barrow No. 65. Days to reach 225 pound weight, 211. Feed for 100 pounds gain, 362. B. Superior barrow No. 63. Days to reach 225 pound weight, 173. Feed for 100 pounds gain, 352. C. Inferior gilt No. 58. Days to reach 225 pound weight, 213. Feed for 100 pounds gain, 421. D. Superior gilt No. 2. Days to reach 225 pound weight, 192. Feed for 100 pounds gain, 367.

tion of the relation between the apparent selection for growth rate and the line differences that occurred was further complicated by the necessity of selecting for faster growth, especially to 72 days of age, as well as for high feed requirements, in order to produce a generation each year in the Inferior line. This made selection for slower growth in the Inferior line appear to be less or the reverse of what it actually was, especially in the case of 72-day weight (tables 1 and 2). That is, the adverse indirect effect on 72-day weight of the selection for higher feed requirements after weaning apparently was stronger than the direct effect of selection for heavier 72-day weights. The lighter average 72-day weight of pigs of the Inferior strains during the first three generations would have had a slight tendency to lower their feed requirements, because of their lower average body weight from 72 days to 225 pounds, compared with pigs of the Superior strain.

The selection for high and low feed requirements was apparently responsible for the Superior line exceeding the Inferior line in rate of growth both before and after 72 days of age (table 2). This is in agreement with the usual assumption that rate and economy of gain are controlled in part by the same inherited physiological differences. The large and significant line difference in 72-day weight disappeared in the fourth and fifth generations, possibly because the parents of fourth generation Inferior line pigs were selected for rapid and economical gains in order to maintain the generation-a-year schedule, and because parents of fifth generation Superior line were selected for slower gain and higher feed requirement due to use of three second-generation boars (table 1). Also the Inferior line sows may have been inherently better milkers but usually bred at too immature a stage of development for this to be apparent, unless the faster growing gilts were selected. Although no carcass comparisons were made, it was evident that the Superior line pigs were fatter at 225 pounds' live weight than the Inferior line pigs, as illustrated in figure 3. Also pigs of the Inferior line were more active and excitable, in line with their higher feed requirements.

Regression of Progeny on Parents

Heritability. The average change in performance of the progeny per unit of change in the average performance of the parents is a direct estimate of heritability or the effectiveness of selection, provided environmental influences on progeny and parents are independent. The present data are especially adapted to this type of analysis, since each litter was from a different sire and dam until the period 1942 to 1945. All litters from parents of known individual performance were used. The regressions were calculated within groups of litters from the same line and farrowing season, and from parents born in the same farrowing season. There were 17 such groups with a total

gain, 421. D. Superior gilt No. 2. Days to reach 225 pound weight, 192. Feed for 100 pounds gain, 307.

of 87 litters and 567 pigs used for analysis of growth rate. Of these, 5 groups consisting of 12 litters and 59 pigs were omitted from the analysis of feed requirements, because one or both of the parents were fed in groups of litter mates rather than individually.

The estimates of heritability from the regressions of progeny on the parental mean are presented in table 3. The estimate of .26 for feed requirement was statistically significant ($P \leqq .05$) and is very similar to the estimate of .24 obtained from the actual line differences resulting from selection among littermates (figure 2). The estimates of .43 for

TABLE 3. REGRESSIONS OF OFFSPRING ON PARENT, WITHIN LINE AND YEAR OF PARENT AND OF OFFSPRING

Variable	D/F	Regression of offspring on			r_{SD}
		Sire (S)	Dam (D)	Mean of parents	
Weight at birth	69	$-.19 \pm .07$	$.06 \pm .09$	$-.23 \pm .13$	$-.26^*$
Weight at 72 days	69	$.02 \pm .09$	$.08 \pm .09$	$.09 \pm .12$	.08
Feeding period	69	$.23 \pm .08$	$.33 \pm .10$	$.47 \pm .12$	.15
Daily gain	69	$.22 \pm .07$	$.29 \pm .09$	$.43 \pm .10$	.15
Feed/Gain	62	$.23 \pm .08$	$.01 \pm .11$	$.26 \pm .12$	.17

* Indicates $P \leqq .05$.

daily gain and .47 for length of feeding period from 72 days of age to 225 pounds' live weight were surely significant ($P \leqq .01$). They were considerably higher than the one for feed requirement, although the difference was not quite significant at the .05 level. Heritability was estimated at .09 for weight at 72 days of age, which was too low for significance in these data. The negative regression of progeny on parents for birthweight is almost too large to be considered an accident of sampling.

Earlier work (Dickerson, 1947) has suggested that many of the genetic factors responsible for economical gaining ability also cause poor milking ability. The regression of offspring on dam would include the dam's transmitted as well as her direct nutritional influence on her pigs, whereas the regression of offspring on sire would measure only the transmitted influence. When these two regressions were calculated separately for feed requirement (table 3), it was found that the regression was .23 on sire but only .01 on dam. The probability of this large a difference by chance alone is only 10 percent. This is interpreted as further evidence that the dams which transmit more economical gaining ability provide poorer nutrition during the suckling period, thus neutralizing their transmitted influence. Doubling the regressions of progeny on sire show that transmitted differences would ac-

count for just as large a proportion of the variation in feed requirements as in daily gain and length of feeding period (.46 vs. .44 and .46, respectively), if it were not for the antagonism between the dam's direct and transmitted influence on feed requirements.

If the dam's direct and transmitted influence in performance of her pigs were uncorrelated, the regression of progeny on dam should be larger than on sire for traits much influenced by heritable differences in the dam's milking ability. This seems to be the case for rate of gain and 72-day weight, although the regressions on dam were not significantly larger than those on sire. In fact, the major portion of heritability of 72-day weight appears to be due to heritability of the sow's nutritional influence. The fact that regression of progeny on dam was significantly smaller for feed requirement than for rate of gain (.01 vs. .29) indicates that lower feed requirements must be caused partly by genes, which do not increase rate of gain but which do reduce milking ability. It seems likely that these are genes that reduce an animal's rate of metabolism and activity, and thereby lower its feed requirements for maintenance and increase its fat deposition, but impair lactation.

There was a slight but nonsignificant tendency for the sire and dam of each litter to be more alike in growth rate and feed requirements than the average (r_{SD}, table 3). This was probably the result of mating individuals that appeared to be similar in sexual maturity. It could account for the regression on mean of parents being smaller than the sum of the regressions on sire and on dam for rate of gain. Curiously, the correlation between birth weights of sires and dams mated was negative and large enough to be significant. Also, the regression of offspring on sire for birthweight was negative and highly significant, compared with a small and non-significant positive regression of offspring on dam. Can it be that the sows whose intrauterine environment produces heavy birth weights transmit genes for smaller birth weights to their pigs?

Genetic correlations. The extent to which two characteristics are merely different expressions of the same genes is indicated by the size of the regression of one character in the progeny on the other character in the parent. To simplify comparisons, these regressions for rate of gain and feed requirement after weaning and for 72-day weight are given in table 4 in terms of the corresponding correlations between unselected progeny and parents. These correlations indicate first of all that there is a statistically significant tendency for the same genetic factors to increase both 72-day weight and daily gain thereafter and to reduce feed requirements. If nursing ability and inherent rate and economy of gain were independent, the precise degree of correlation between genetic deviations in economy and rate of gain could be estimated

as indicated by Hazel *et al.* (1943) from the correlations in tables 3 and 4, e.g. as

$$r(G_x G_y) = \frac{r_{Y_o X_s} + r_{X_o Y_s}}{\sqrt{r_{Y_o Y_s} \cdot r_{X_o X_s}}} .$$

However, we have already presented evidence that poor suckling ability and inherently low feed requirements are associated. This is further supported

TABLE 4. ESTIMATES OF CORRELATIONS[1] BETWEEN ONE VARIABLE FOR THE PROGENY (*c*) AND ANOTHER VARIABLE FOR UNSELECTED SIRES (*s*), DAMS (*d*) AND THE PARENTAL MEAN (*p*)

Variable	Degrees of freedom	$r_{Y_o X_s}$	$r_{Y_d X_d}$	$r_{Y_p X_p}$	$r_{X_o Y_s}$	$r_{X_d Y_d}$	$r_{X_p Y_p}$
Feed/Gain (X) with:							
Daily gain (Y)	62	−.22**	−.07	−.29*	−.26**	−.19*	−.40**
72-day wt. (Y)	62	−.11	.04	−.09	−.20*	−.14	−.31**
Birth wt. (Y)	62	.09	−.15	−.00	−.10	−.07	−.23*
Daily gain (X) with:							
72-day wt. (Y)	69	.13	.12	.23*	.11	.16	.25*
Birth wt. (Y)	69	−.14	.10	−.08	.10	−.00	.15
72-day wt. (X) with birth wt. (Y)	69	−.17	.18	.02	−.00	−.15*	−.18

[1] These estimates were obtained by multiplying the regressions of average of progeny on sire, dam and mean of parents by the ratio of the standard deviations of the two variables among unselected progeny, e.g. $b_{Y_o X_s} \frac{\sigma_{X_o}}{\sigma_{Y_o}} = r_{\bar{Y}_o X_s} \frac{\sigma_{\bar{Y}_o}}{\sigma_{X_s}} \cdot \frac{\sigma_{X_o}}{\sigma_{Y_o}} = r_{Y_o X_s}$, since $b_{\bar{Y}_o X_s}$ is a valid estimate of $r_{\bar{Y}_o X_s} \frac{\sigma_{\bar{Y}_o}}{\sigma_{X_s}}$ in a population where values of X_s are unselected and $\sigma_{X_s} = \sigma_{X_o}$. The three standard deviations were calculated from the totals for components of variance in table 6.

* Indicates $P \leq .05$.

** Indicates $P \leq .01$.

by the finding (table 4) that the correlations of both 72-day weight and rate of gain of progeny with feed requirement of dam were considerably (though not significantly) less negative than with feed requirement of sire. Also, the negative correlations of feed requirement of progeny with 72-day weight and rate of gain of dam were a little smaller than with rate of gain of sire. They should have been larger because of heritable variation in the dams' nutritional influence, except for sampling error or for a tendency of ability to gain rapidly to be mildly antagonistic to good milking ability.

The estimate of genetic correlation, mentioned above, between feed requirement and rate of gain ($r_{G_f G_r}$) is much too large, especially when calcu-

lated from the correlations between offspring and dam. The bias is evidently due to the dam's transmitted influence on feed requirements being almost exactly cancelled by her direct nutritional influence, leaving a net regression of .01. For example,

$$r_{G_fG_r} = \frac{-.07 - .19}{2\sqrt{(.29)(.01)}} = -2.41$$

from the dam correlations but only

$$\frac{-.22 - .26}{2\sqrt{(.22)(.23)}} = -1.07$$

from the sire correlations, the difference being -1.34. Since this difference of -1.34 corresponds to about three-fourths of the bias in the estimate from the dam correlations, the corrected estimate would be something like $-.6$. Because of the uncertainty and magnitude of the bias and the large sampling errors, estimates of genetic correlation were not attempted from table 4.

The correlations in table 4 indicate that the heavier parents at birth had progeny that gained more rapidly and economically after 72 days of age, but the heavier dams at birth had lighter pigs at 72 days. Since birth weight is largely a characteristic of the dam these correlations suggest that the genes responsible for good uterine nutrition also tend to cause rapid and economical post-weaning gain but poor suckling ability. Sires with the heavier 72-day weights and the more rapid and economical gains tended to transmit lighter birth weight to their progeny, whereas the opposite association existed between dam and progeny. The difference between the sire and dam correlations was significant ($P = .02$) for birth weight of progeny with 72-day weight, but not with rate or economy of gain. Apparently, the more rapid and economical post-natal growth of the parent enables the dam to provide better uterine nourishment for her litter but is associated with slower inherited prenatal growth rate in the pigs.

Variance Due to Sire, Litter, Lot and Intra-lot Differences

Sources of variation. This part of the analysis included all litters for which feed records were taken. The analysis was made within groups of pigs from the same line and year and from dams born the same year to avoid confusing the effects of these variables with those due to sire and litter. The mean squares from each source are given in table 5A and their expected composition is shown in table 5B. Differences between lots in the same litter were significantly larger than intra-lot differences for weight at birth and 72 days. This tendency was less pronounced and lacked significance during the

only years (1942–1944) when more than one pig was fed in a lot. However, there was a real tendency for differences in weight at birth and 72 days to be larger among the individually fed litter mates in earlier years than among litter mates fed in the same lot during 1942–1944. Litter differences within sire progenies were not significant, but almost no information was available on this point because each sire usually had but one litter. Differences be-

TABLE 5. ANALYSIS OF VARIATION WITHIN LINES AND YEAR OF PROGENY AND OF DAM

A. Mean Squares

Source of variation	Degrees of freedom	Pig's weight—lbs.		Feeding period —days	Daily gain pounds	$\frac{\text{Feed}}{\text{Gain}} \times 100$ pounds
		At birth	At 72 days			
Sire progenies	75	.637**	212.9**	2620**	.1436**	2730**
Litters of same sire	12	.428	53.5	459	.0298	655
Lots in same litter	530	.13**	38.2**	444	.0292	916
Pigs in same lot	186	.081	27.6	444	.0268	—

B. Expected Composition of Mean Squares

Source of variation	Composition[1]
Sire progenies	$E+1.432I+6.564D+6.993S$
Litters of same sire	$E+4.528L+6.479D$
Lots in same litter	$E+1.080L$
Pigs in same lot	E

** Indicates $P \leq .01$.

[1] See Hetzer, Dickerson and Zeller (1944) for method used in calculating coefficients of variance components in the mean squares.

tween sire progenies were large and highly significant, compared with intra-litter variation.

Since little information on differences between litters by the same sire was available, it was not possible to estimate the variances from the sire and from the dam influences separately. The sire and dam variances together (*D* and *S* in table 6) account for about half of the additive genetic variance, but also include all of the variance from environment common to litter mates. Thus, doubling the correlation between litter mates (table 6, bottom) would over-estimate the fraction of the total variance due to the pig's own genes by twice the fraction of the total variance due to environment common to litter mates. The correlation between litter mates was larger for daily gain and length of feeding period (.37 and .42) than for feed requirements (.23). This

indicates that litter environment and the pig's own genes, together, have less influence on feed requirements than on rate of gain, which is what would be expected if the dam's transmitted and direct nutritional influences on feed requirements of her pigs tended to cancel one another.

Simple correlations. The simple correlations between each pair of variables studied are presented in table 7. The total correlation of −.66 between daily gain and feed requirement is about what usually has been found in studies of swine feeding data. The correlation of −.19 between 72-day weight and feed requirement was entirely due to the correlation of −.60 between 72-day weight and length of feeding period. In fact, multiple re-

TABLE 6. COMPONENTS OF VARIANCE

Source	Pig weight, lbs.		Feeding period, days	Daily gain, lbs.	$\frac{\text{Feed}}{\text{Gain}} \times 100$ lbs.
	At birth	At 72 days			
Sire+dam=$.97D+1.03S$	.072	25.3	320.9	.0168	268
Lots=L	.046	9.8	.3	.0022	916[1]
Intra-lot=E	.081	27.6	444.1	.0268	—
Total=$.97D+1.03S+E+L$	.199	62.7	765.3	.0458	1183
Correlation between litter mates=$\frac{.97D+1.03S}{.97D+1.03S+E+L}$	.36**	.40**	.42**	.37**	.23**

** Indicates $P \leq .01$.
[1] $E+1.08L$.

gression indicates that, independent of its effect on length of feeding period, heavier 72-day weights were associated with higher feed requirements, i.e., standard partial regression of feed on 72-day weight was .33 compared with .87 on feeding period. This is what might be expected if the dams whose heavy milk production increases 72-day weights also transmit a tendency to faster rate of metabolism and greater activity. Also, the fact that heavier pigs at 72 days have a slightly higher average body weight to be maintained during the feeding period could be partly responsible. Daily gain after 72 days was more important than 72-day weight in determining length of feeding period, the standard partial regression being −.85 on daily gain and −.23 on 72-day weight. The lack of complete multiple correlation (R^2 of period with 72-day weight and daily gain=.94+) presumably may be ascribed to curvilinearity in the regression of period on daily gain.

The correlation of 72-day weight with daily gain, length of feeding period,

TABLE 7. SIMPLE CORRELATIONS, WITHIN LINE AND YEAR OF OFFSPRING AND OF DAM

Source of variation	Degrees of freedom	Feed/Gain with:				Daily gain with			Feeding period with		72-day weight with birth weight
		Daily gain	Feeding period	72-day weight	Birth weight	Feeding period	72-day weight	Birth weight	72-day weight	Birth weight	
Sire progenies	74	−.73**	.77**	−.41**	.07	−.96**	.59**	.04	−.72**	−.17	.61**
Lots in same litter	529	−.64**	.64**	−.07	−.13**	−.94**	.35**	.13**	−.50**	−.34**	.67**
Pigs in same lot	185					−.95**	.37**		−.61**		
Total	802[1]	−.66**	.67**	−.19**		−.95**	.44**		−.60**		
Net sire and dam influence ($.97D+1.03S+.05L$)		−.78	.83	−.54	.07	−.96	.65	.02	−.77	−.07	.29

[1] Degrees of freedom are 617 for the correlations involving feed requirements.
** Indicates $P \leq .01$.

and feed requirements after 72 days was significantly closer among means of sire progenies (74 degrees of freedom) than among pigs or lots within litters (529 degrees of freedom). This indicates that the sire and dam influence on rate of gain was more similar before and after 72 days of age than was the case for intra-litter environmental influences on rate of gain, in agreement with the findings of Hazel *et al.* (1943).

There was a highly significant tendency among litter mates (529 degrees of freedom) for the heavier pigs at birth to be heavier at 72 days and to grow more rapidly and economically thereafter. However, among means of sire progenies, the correlation of birth weight with economy was reversed and those of birth weight with daily gain and feeding period were smaller and not significant.

The correlations between each pair of variables for the net sire and dam influence is shown in the bottom line of table 7. These correlations are genetic except for environmental variation in the dam's direct nutritional influence. They are significantly larger than the total correlation except for the association of daily gain with feed requirement and with length of feeding period and those involving birth weight.

Interpretation and Application

Selection Procedures

This investigation was undertaken to discover how selection can be used most effectively to improve economy of post-weaning gain in swine. It was found from regression of progeny on mean of the parents (table 3) that the heritability of differences between pigs from the same strain and farrowing season was less (.26) for feed requirements than for rate of gain (.43) from 72 days of age to 225 pounds in weight. The observed correlation of $-.78$ between feed requirements and rate of gain for the sire plus dam influence (table 7) was the best estimate of the correlation between heritable variation in the two characters available from the present data. Therefore, rate of gain and feed requirements appear to be about equally correlated with heritable differences in feed requirements (i.e. $r_{G_fR} = -.78\ \sqrt{(.43)} = -.51$ and $r_{G_fR} = \sqrt{.26} = .51$). If true, this means that selection based on rate of gain would be just as effective in improving economy of gain as selection based on individual feed records and considerably more effective in improving rate of gain (i.e. $r_{G_rR} = \sqrt{.43} = .66$ and $r_{G_rF} = -.78\sqrt{.26} = -.40$.) The multiple correlation ($R_{G_f \cdot FR} = .56$ when $r_{FR} = -.66$) indicates that selection based on both feed and gain data would be about 10 percent more effective than either alone in improving economy of gain.

It appears that the genetic factors that lower an individual's feed requirement without increasing its rate of gain to any extent also cause a sow to

provide poorer nourishment for her pigs. Thus, in selecting directly for economy of gain, part of the improvement in the pig's own inherent economy of gain would be cancelled by the poorer nutrition during the suckling period. The genes that increase rate of gain appear to be more nearly independent of those that reduce milking ability. However, part of the apparently higher heritability of rate of gain may be due to a tendency for the environmental influences that increase the dam's own rate of gain to make her more precocious in nourishing her pigs. To whatever extent that is the case, selection on rate of gain is less efficient than was pictured above in improving economy of gain, relative to selection based directly on individual feed requirements. A decline in the dam's nutritional influence (milk production) presumably would have an adverse effect on a related important economic character, the number of pigs raised per litter. This would be another reason for basing actual selection for economy of gain on the rate of gain more than on the feed requirements. The fact that no difference in litter size appeared between the Superior and Inferior lines may be simply because the gilts selected for breeding were the faster growing ones in the Superior line, but not in the Inferior line.

Because of its low heritability (.09, table 3) and only moderate genetic correlation with feed requirements (−.54, table 7), weight at 72 days apparently would be less than one-third as accurate a basis of selection for economy of gain as daily gain or feed requirements from 72 days to a 225-pound live weight ($r_{G_w C_f} = .16$ compared with .51). Although the estimated heritability of .09 was too small for statistical significance, it agrees rather well with estimates from other studies. The pig's own genes apparently accounted for about .03 and genetic differences in the sow's nutritional influence for about .12 of total variation in 72-day weight. Since sire and dam together accounted for .40 of the variation in 72-day weight (table 6), differences in litter environment (largely nutritional were approximately one-third heritable (i.e. .12/.40 − .015). Similarly, Bywaters (1937) obtained a regression of offspring on dam of .077 and a paternal half-sib correlation of .017 for 56-day weight. This would indicate that the pig's own genes accounted for .07 (i.e. 4×.017) and heritable differences in the dam's nutritional influence for .09 (i.e. 2×.077 − 4×.017) of the variation in 56-day weight, with litter environment about one-fourth heritable (i.e. .09/.36). Hetzer (1942) and Nordskog *et al.* (1944) found the intraline sire influence on 56-day weight was negligible, whereas Baker *et al.* (1943) found that the sire and line influence together indicated that .15 of the variation in 56-day weight was heritable, again suggesting that much of the heritability of 56-day weight is due to heritable differences in the nutritional influences of the dam. Selection programs based on weaning weights of individuals and of

litters, therefore, would be reasonably effective in improving the mothering ability of sows but would be relatively ineffective in improving individual gaining ability.

The significant negative regression of progeny on sire for birthweight suggests that the dams which provide good prenatal environment transmit poor prenatal growing ability to their pigs. Since maternal environment overshadows the pig's inherent growth rate during gestation, the sires that were themselves heavier at birth might transmit lighter birth weight to their progeny. However, the dams that were heavier at birth also would tend to have received inheritance for better uterine environment, offsetting their transmitted effect on birth weight. These relationships apparently differ for 72-day weight and daily gain after 72 days in that the pig's own inherent growth rate has become more important and the dam's environmental influence less important.

Bias in Heritability Estimates

The present study provides excellent illustrations of the bias that is introduced in different methods of estimating heritability by heritable differences in the dam's environmental influence and their correlation with the dam's transmitted influence. Aside from a controlled selection experiment, the regression of progeny performance on the mean performance of the two parents is probably subject to less bias than other methods commonly used. It is biased only to the extent that (1) environmental variation in the dam's own performance affects the environment she provides for her pigs, and (2) the change in the offspring is due to non-additive effects of certain genetic combinations transmitted by the immediate parents, which will be lost as these combinations disintegrate in later generations. Even when these two sources of bias are negligible, doubling the intra-sire regression of progeny on dam (Lush, 1940) overestimates actual heritability (i.e. the average for selection in both sexes) by the fraction of the total variance due to half the variance from heritable differences in the dam's environmental influence plus that due to covariance between the dam's transmitted and environmental influence. Doubling the regression of progeny on sire (when sire's and dam's performance is uncorrelated) underestimates heritability to the same degree that regression on dam overestimates it. Thus, one would expect regression on dam to be larger than regression on sire for characters much influenced by maternal environment if the correlation between the dam's transmitted and environmental influences is small or positive. This was found to be the case for measures of growth rate, but the difference was completely reversed for feed requirements, indicating a strong negative correlation between the direct and transmitted maternal influences.

Doubling the correlation between full-sibs overestimates actual heritability by 2 times the non-heritable part and by 1.5 times the heritable part of the environmental influence which is alike for litter mates, plus 0.5 times the part due to covariance between the dam's transmitted and environmental influence. Hence, it is practically worthless in estimating heritability for traits much influenced by environment common to the whole litter. Multiplying the correlation between paternal half-sibs in a noninbred population by four underestimates heritability by 0.5 of the fraction of variation from heritable differences in the dam's environmental influence plus 1.5 times the fraction due to covariance between the direct and transmitted influence of the dam. This method was unavailable in the present data because each sire usually had only one litter. When the covariance between the direct and transmitted dam's influence is strongly negative and the pig's own genes are important, as for feed requirement after 72 days of age, this method will actually overestimate heritability. It ignores the negative covariance, except as it makes the net dam variance smaller, and thus increases the correlation between paternal half-sibs.

Estimates of heritability from a controlled selection experiment also may have limitations. In the present instance, selection was largely between litter mates because of the attempt to avoid inbreeding by using a boar and gilt from each litter raised. The variance among litter mates is less than that in the whole population by half of the part due to the pig's own genes (G) and by all of the part due to litter environment (G_m+E_m) and to the covariance between the dam's transmitted and environmental influence

$$\left(\text{i.e. less by } \frac{V(G)}{2} + V(G_m) + V(E_m) + \text{Cov}\,(GG_m)\right).$$

Thus the heritability of differences among litter mates would be

$$H_2 = \frac{.5V(G) + .5\ \text{Cov}\,(GG_m)}{.5V(G) + V(E)}$$

in contrast with the heritability of differences in the whole population, which would be

$$H_1 = \frac{V(G) + .5V(G_m) + 1.5\ \text{Cov}\,(GG_m)}{V(G) + V(G_m) + \text{Cov}\,(GG_m) + V(E_m) + V(E)}.$$

Cov (GG_m) was strongly negative for feed requirements. Hence the numerator may be considerably more than half as large for H_2 as for H_1. In these data the variance in feed requirements among litter mates was about .77 as large as the total variance (table 6). Therefore, selection among litter

mates could easily be more than two-thirds as effective as selection between pigs from different litters

$$\left(\text{i.e.}\ \frac{H_2}{H_1} = \frac{.5}{.77} = 2/3\right).$$

The actual results indicate that after the first year, the largely intra-litter selection was about .24 effective compared with the estimate of .26 for H_1 from regression on mean of the parents. The .05 fiducial limits for the observed H_1 were .03 and .50 so that the real difference between H_1 and H_2 may well be larger or smaller than was found.

Morris, Palmer, and Kennedy (1933) have reported results of selecting for high and low efficiency of food utilization in two strains of rats. They did not attempt to calculate the effectiveness of selection from the amount of selection practiced and the resulting line differences. This seemed worth doing because of the similarity to the present swine experiment. Using the methods outlined for pigs, it was found that 46 percent of the individual differences in feed utilization in these rats were heritable, compared with only 24 percent for feed per unit gain in the present swine data. It seems likely that the effectiveness of selection in the swine experiment was reduced by selecting largely between litter mates, and by choosing the faster gaining pigs among those with low feed requirements for breeding in the Inferior line in order to produce one generation each year in both strains. Also, it is possible that the antagonism between milking ability and inherently low feed requirements is less pronounced in rats than in swine, because swine have been pushed to a more extreme efficiency by continuous selection for this characteristic. If so, food utilization would tend to be more highly heritable in rats than in swine.

Summary

Results are presented from selecting for high and for low individual feed requirements per pound of gain in two strains of Duroc swine for five generations, beginning with a common foundation stock in 1937. All pigs from each litter were full-fed a mixed ration in individual pens with concrete floors, from 72 days of age to a live weight of 225 pounds. To minimize inbreeding, one boar and gilt were usually selected from each of the 8 litters in each strain every year, and sib matings were avoided. Thus, selection was based largely on differences between litter mates. These differences were found to be about 24[2] percent heritable, judging by the amount of selection actually practiced and the resulting mean difference between unselected progeny of the two strains.

[1] Indicates $P \leq .01$.
[2] Indicates $P \leq .05$.

Heritability of differences between non-sibs was estimated from regression of progeny on mean of the parents within strain and year. In percent, the estimates were: 26^3 for feed requirements, 43^2 for daily gain and 47^2 for length of feeding period, from 72 days to a live weight of 225 pounds; 9 for weight at 72 days and −23 for weight at birth. Regression of progeny on sire and dam, separately, revealed that the lower heritability of feed requirements relative to daily gain was due to a much stronger negative correlation between the dam's transmitted and environmental influences on the feed requirements than on the growth rates of her pigs. Such a negative correlation for prenatal growth rate may explain why heritability of birth weight was significantly negative among sires, but positive among dams, since the sires that were heavier at birth would be from dams which provided good uterine nutrition but transmitted a slower growth impulse.

Regressions of one character in the progeny on another character in the parents indicated that the same genetic factors tend to increase 72-day weight and the rate and efficiency of gain thereafter. They also provided further evidence for incompatability of good suckling ability with inherently lower feed requirements and less noticeably, with inherently rapid growth.

The correlation between litter mates, among progeny of the same strain and year of dam and progeny, was $.23^2$ for feed requirement, $.37^2$ for daily gain, $.42^2$ for length of feeding period, $.40^2$ for 72-day weight and $.36^2$ for birth weight. The lower litter mate correlation for feed requirements is attributed to the opposite effects of the dam's transmitted and nutritional influences. Similarity in maternal environment was largely responsible for the large litter mate correlations for weight at birth and at 72 days, whereas likeness in genetic constitution accounted for more of the litter mate correlations for growth rate and feed requirement after 72 days.

The best estimates obtained for genetic correlation were those for the combined sire and dam influence as follows: feed requirement was correlated $-.78^2$ with daily gain, $.83^2$ with feeding period and $-.54^2$ with 72-day weight; daily gain was correlated $-.96^2$ with feeding period and $.65^5$ with 72-day weight; and feeding period was correlated $-.77^2$ with 72-day weight. These are generally higher than the corresponding total correlations of $-.66^2$, $.67^2$, $-.19^2$, $-.95^2$, $.44^2$ and $-.60^2$ respectively. Evidently, hereditary and maternal influences on performance were more constant throughout the growing period than intralitter environmental influences.

These results indicate that selection based on rate of grain from weaning to market weight would be nearly as effective in improving economy of gain as selection based directly on individual feed requirements. The genetic factors that lower feed requirements, without increasing rate of gain, also apparently impair the suckling ability of sows. This indirectly increases post-

weaning feed requirements enough to offset the extra reduction in the pig's own inherent feed requirements. Selection based on individual and litter weights at weaning would be moderately effective in improving the suckling ability of sows but relatively ineffective in increasing the rate and efficiency of post-weaning gains.

Literature Cited

Baker, M. L., L. N. Hazel and C. F. Reinmiller. 1943. The Relative Importance of Heredity and Environment in the Growth of Pigs at Different Ages. JOURNAL OF ANIMAL SCIENCE, 2: 3–13.

Bywaters, J. H. 1937. The Hereditary and Environmental Portions of the Variance in Weaning Weights of Poland China Pigs. Genetics, 22: 457–468.

Dickerson, G. E. 1947. Composition of Hog Carcasses as Influenced by Heritable Differences in Rate and Economy of Gain. Iowa Agr. Exp. Sta. Res. Bul. (*In press*). Abst. in JOURNAL OF ANIMAL SCIENCE, 2: 357, 1943.

Evvard, John M., M. G. Snell, C. C. Culbertson and Geo. W. Snedecor. 1927. Correlations between Daily Gains and Feed Requirements of Growing and Fattening Swine. Amer. Soc. An. Prod., Proc., 1927: 2–9.

Hazel, L. N., Marvel L. Baker and C. F. Reinmiller. 1943. Genetic and Environmental Correlations between Growth Rates of Pigs at Different Ages. JOURNAL OF ANIMAL SCIENCE 2: 118–128.

Hetzer, H. O. 1942. Differences in Mothering and Nursing Ability of Sows as a Cause of Differences in Some Weights of Their Pigs. (Abst.) JOURNAL OF ANIMAL SCIENCE, 1: 71.

Hetzer, H. O., G. E. Dickerson and J. H. Zeller. 1944. Heritability of Type in Poland China Swine as Evaluated by Scoring. JOURNAL OF ANIMAL SCIENCE, 3: 390–398.

Krider, J. L., B. W. Fairbanks, W. E. Carroll and E. Roberts. 1946. Effectiveness of Selecting for Rapid and for Slow Growth in Hampshire Swine. JOURNAL OF ANIMAL SCIENCE, 5: 3–15.

Lush, J. L. 1936. Genetic Aspects of the Danish System of Progeny-Testing Swine. Iowa Agr. Expt. Sta. Res. Bul. 204.

Lush, J. L. 1940. Intra-sire Correlations or Regressions of Offspring on Dam as a Method of Estimating Heritability of Characteristics. Amer. Soc. An. Prod., Proc., 1940: 293–301.

MacArthur, John W. 1944. Genetics of Body Size and Related Characters. I. Selecting Small and Large Races of the Laboratory Mouse. Amer. Nat. 78: 142–157.

Marble, D. L. and G. O. Hall, 1931. A Statistical Analysis of the Results of Breeding High-line and Low-line Leghorns. Cornell Agric. Expt. Sta. Bull. 533, pp. 1–38.

Morris, H. P., L. S. Palmer and Cornelia Kennedy. 1933. Fundamental Food Requirements for Growth of the Rat. VII. An Experimental Study of Inheritance as a Factor Influencing Food Utilization in the Rat. Minn. Agric. Expt. Sta. Tech. Bull. 92.

Nordskog, A. W., R. E. Comstock and L. M. Winters. 1944. Hereditary and Environmental Factors Affecting Growth Rate in Swine. JOURNAL OF ANIMAL SCIENCE, 3: 257–272.

"Student." 1934. A Calculation of the Minimum Number of Genes in Winter's Selection Experiment. Annals of Eugenics, 6: 77–82.

Winter, F. L. 1929. Mean and Variability as Affected by Continuous Selection for Composition in Corn. Jour. Agr. Res., 39: 451-476.

A STUDY OF FACTORS AFFECTING SURVIVAL FROM BIRTH TO WEANING AND TOTAL WEANING WEIGHT OF THE LITTER IN SWINE[1]

L. M. WINTERS, J. N. CUMMINGS, AND H. A. STEWART[2]
University of Minnesota

PRODUCTIVITY in brood sows during the pre-weaning period is measured by fertility, survival of the pigs born, and milk production. All three of these factors contribute to a large extent to the total weaning weight of the respective litters and are of individual economic importance to the hog producer. Therefore, from the breeder's standpoint, it is important to know to what extent these factors are related to one another or influenced by other factors in order to select effectively for greater productivity in the breeding herds already established or in the development of improved lines.

High survival of the pigs born is an important goal of all swine raisers. Even though improved methods in management and certain methods of breeding have helped to lower the death loss of little pigs the problem is still of major importance. From a study of several herds under varying conditions Kernkamp (1943, 1946) found that the average loss of little pigs during the suckling period was about 25 percent and that the losses were due to more than 35 different diseases, disorders, or conditions. The death rate was highest in pigs up to one to two weeks of age and was reduced as they grew older.

The early experiments in guinea pigs by Wright (1922) and in swine by McPhee *et al.* (1931) and others have shown that a rapid increase in inbreeding had a deleterious effect upon the vitality of the newborn and thus reduced survival considerably in most instances. They also found that there was a decided decrease in weaning weights of the young as the inbreeding increased. This was reflected in a lower total weaning weight of the litter as inbreeding had decreased the size of the litters. Winters *et al.* (1943), by the use of a flexible program of inbreeding and rigid selection for all traits connected with vigor, reported an ability to maintain survival and weaning weight at a relatively high level as the inbreeding increased. It is generally

[1] Paper No. 2329, Scientific Journal Series of the Minnesota Agricultural Experiment Station in cooperation with the Regional Swine Breeding Laboratory, Ames, Iowa, Bureau of Animal Industry, U. S. Department of Agriculture.

[2] H. A. Stewart is Professor in the Department of Animal Industry, North Carolina State College, Raleigh, North Carolina. Funds for the statistical analyses of this study were provided in part by a Grant in Aid of Research of the Graduate School, University of Minn. The authors are indebted to Mrs. Helen Feldman for her assistance in making many of the statistical calculations included in this paper.

acknowledged also that crossbreeding increases the vigor of new born pigs which is reflected in higher survival and higher weaning weights.

There is apparently a relationship between size of litter and survival and, according to most reports, a higher percentage of the pigs born die before weaning in the larger litters. Studies of Bywaters (1937) on Poland China hogs, indicate that litter size has little effect on average weaning weight for he found that only three percent of the total variance in the average weaning weights was attributable to the size of the litter. In a report of a study on Large White hogs, Smith and Donald (1937) suggest that there is a relationship between fertility and milk production, the latter increasing with fertility but not to a large enough extent to give each pig in a large litter the the same chance as those in the small litter. They concluded (in accordance with other reports) that there was too much variation within the litters to account for much of a relationship between litter size and individual weaning weight. Undoubtedly, the relationship between fertility and milk production is quite variable in itself; for, even though his observations were limited, Donald (1937) was able to demonstrate considerable differences in milk production between sows of the same fertility. Later he (Donald, 1939) showed that the sow's influence on the growth of the pig up to weaning was great enough to cover up the individual pig effects. The influence of milk production on weaning weights is also brought out in the study by Zeller *et al.* (1937).

Weaver and Bogart (1943), Meyer (1940), and Lüthge (1933) found that there was a greater percentage of pigs raised in litters having a higher average birth weight, but this may have been associated more with size of litter as the smaller litters were composed of larger pigs. Wright (1922) indicated that there might be some physiological interrelation between birth weight, gain, and size of litter. A positive correlation between birth weight and weaning weight in pigs was indicated by Weaver and Bogart (1943) and Lush and Culbertson (1931).

Among the most important effects upon survival are those due to heredity and individuality of the parents. Wright (1922) first brought this out in the inbreeding study with guinea pigs where he found that the average success of the different families in raising their young was not correlated with weight nor with size or frequency of litters. He also found no significant correlation between the percentage born alive and that raised although success or failure in each separately was undoubtedly characteristic of the families. Hodgson (1935) points out that temperament of the sow is extremely important in her rearing ability and he found definite line differences in this respect which were reflected quite unmistakably in the results obtained. Lush *et al.* (1933), Lush and Molln (1942), Lüthge (1933) and Olbrycht (1943) also re-

ported that individual differences between sows had considerable effect. In an inbreeding study with Chester Whites, Hetzer *et al.* (1940) found significant differences between individual sires in the number of pigs alive at 28 days and at 70 days even though there were no differences in the size of litters at birth.

In the present study it was proposed to determine what effects inbreeding, size of litter, and birth weight had upon survival of the litter from birth to weaning and upon the total weaning weight of the litter in the hogs used in the Minnesota swine breeding project.

Materials and Methods Used

The data used included those collected from the farrowing and preweaning records from 1937–1944 of the hogs maintained at six of the sub-stations

TABLE 1. MEAN VALUES OF PERCENTAGE OF INBREEDING, SIZE OF LITTER AT BIRTH, SURVIVAL OF THE PIGS FROM BIRTH TO WEANING, BIRTH WEIGHT PER PIG IN EACH LITTER, AND TOTAL WEANING WEIGHT OF THE LITTERS

Groups[1]			No. of sire groups	No. of litters	Inbreeding of dams, %	Inbreeding of litters, %	No. of pigs born alive per litter	Survival, %	Birth wt. per pig in each litter	Total 56-day wt. of litter, lbs.
Station	Breed	Lines								
Cent.	P. C.	All	19	96	9.1	22.0	6.8	69.3	2.71	135.8
W. C.	P. C.	All	44	170	18.2	24.5	7.8	79.7	2.96	204.2
N. C.	No. 1		29	214	15.0	20.8	8.8	71.8	2.80	189.8
N. E.	No. 2		1	4	18.8	0	9.0	91.7	2.67	274.8
N. W.	P. C.	All	29	129	21.5	26.2	6.2	61.7	2.74	114.0
	No. 2		6	45	12.3	14.4	8.0	64.3	2.69	140.1
S. E.	No. 1		1	2	25.5	29.5	9.0	55.6	2.72	189.5
	No. 1XP. C.		1	2	75.0	0	6.0	100.0	3.94	276.5
	P. C.	M	10	49	69.0	71.5	5.6	70.0	3.31	135.3
		C	3	18	13.6	27.4	5.5	34.3	2.33	50.2
		G	2	16	11.1	19.5	6.4	52.0	2.96	83.9
Total			145	745	19.6	25.7	7.47	70.4	2.84	161.4

[1] Total No. pigs born alive = 5562. Total No. pigs weaned = 3918.

of the Minnesota Agricultural Experiment Station. Only gilt litters farrowed in the spring were used in order to eliminate most of the age and seasonal effects. Altogether, 745 litters composed of 5562 pigs born alive, of which 3918 survived to weaning, were included in the study. These pigs were from 14 inbred lines of which 12 were developed within the Poland China breed, one of them (Minn. No. 1) was developed from a Landrace-Tam-

worth crossbred foundation (Winters *et al.*, 1943), and the other line (Minn. No. 2) is being developed from a Poland China-Yorkshire crossbred foundation. In addition, eight miscellaneous Poland China line-crosses are included. The methods of keeping records, the data collected, feeding and managerial practices, and the breeding program are all described by Winters *et al.* (1943).

Table 1 gives the mean values of the factors analyzed by different breed and line groups. Survival was determined by the ratio of the number of pigs alive at weaning (56 days of age) to the number born alive in each litter and was expressed in percentage. The inbreeding coefficients for both the dams and their litters were calculated according to Wright's (1922 b) method.

The litters were grouped by years and by sires, and intra-sire, intra-year regressions calculated from analyses of covariance were used to determine the relationships between the factors referred to above and survival and total weaning weight of the litter. The intra-sire variance and covariance were used in order to eliminate the herditary effects transmissible by the different boars. The values for survival were transformed from percentage to angles expressed in degrees. These transformations are given in table form by Snedecor (1940) and the advantages and reasons for using transformed values instead of the actual percentages are discussed by him and by Clark and Leonard (1939).

Results and Discussion

Factors influencing survival

The first phase of the study was made to determine the effects of the inbreeding of the dam, the inbreeding of the litter, size of litter at birth, and birth weight of the pigs on survival. These relationships are expressed by

TABLE 2. WITHIN GROUP SIMPLE AND PARTIAL REGRESSIONS:—INBREEDING OF DAM (*b*), INBREEDING OF LITTER (*c*), NUMBER OF PIGS ALIVE AT BIRTH (*d*), SURVIVAL (*g*, *transformed value in degrees*), AND AVERAGE BIRTH WEIGHT PER PIG (*h*) (THE UNIT INCREASE OR DECREASE IN INBREEDING IS 1.00 OR 100 PERCENT)

Simple regressions	Partial regressions	Partial regressions	Partial regressions
g/b 8.55	g/b.c 12.36	g/b.d 1.61	g/b.cd 7.02
g/c −7.16	g/c.b −12.30	g/c.d −14.86	g/c.bd −17.73
g/d −1.66**	g/d.b − 1.66**	g/d.c − 1.69**	g/d.bc − 1.68**
	g/d.h − 0.77		
g/h 17.05**	g/h.d 15.70**		

** Significant at 1 percent level.

simple and partial regressions in table 2. Intra-sire regressions were used in all cases.

From the above table it is evident that the effects of inbreeding, either of the dams or their litters, on survival are not statistically significant. In addition, these regressions are quite small indicating only slight effects or trends when one considers that the unit increase for inbreeding used to calculate the above regressions is 1.00 or 100 percent. Taking the regression g/b as an example, there was only 8.55 degrees (equivalent to 2.2 percent) increase in survival accompanying 100 percent increase in the inbreeding coefficient or 0.855 degrees (equivalent to 0.02 percent) increase in survival for ten percent increase in inbreeding. However, it is interesting to note that the regressions of survival on inbreeding of the dam are in the positive direction while those of survival on inbreeding of the litter are all negative. This might be explained by the fact that during the entire course of the swine breeding project at Minnesota, considerable emphasis has been placed upon the selection of future breeding stock from litters showing the greatest vitality which has tended to maintain a certain level in survival regardless of the depressing effects of inbreeding in the litters. The above data for the dams are biased in so far as only enough gilts from highest performing litters have been retained for the succeeding generations, and consequently breeding records on all females produced were not available. When considering this fact and the one that the inbreeding increased progressively with each succeeding generation, the positive relationship between inbreeding of the dams and survival definitely indicates that selection for higher survival has been effective. Further evidence for the above fact was found in another study by the authors where they obtained the relatively high heritability estimate for survival of 40.3 percent for the same populations from which these data were drawn (Cummings *et al.* 1946). Also, a more flexible program of increasing the inbreeding and of selection has been used in this project than that used by other workers who obtained rapid decline in vigor due to inbreeding.

An increase in the size of litter had a depressing effect upon survival. However, its effect was quite small and about the same when inbreeding of the dams and litters was held constant. When the effects of the average birth weight were held constant this relationship was no longer statistically significant indicating that average birth weight was a more important factor than either size of litter or inbreeding.

From the regressions, $g/d.h$, g/h and $g/h.d$ it is seen that the chances for survival were greatest for the heavier pigs at birth regardless of the size of litter even though there was a significant negative correlation between average birth weight and size of litter ($r = -.32$). This indicates a strong physiological interrelationship.

Factors influencing total weaning weight of the litter

The effects of the same factors referred to above on total weaning weight of the litter at 56 days of age are given by intra-sire regressions in table 3.

Again, neither the inbreeding of the dams nor the inbreeding of the litter had a significant effect upon total weight of the litter at weaning. The regression i/c was significant at the 5 percent level, but apparently the effects of c included more than those associated with just inbreeding of the litter. This relationship does not hold up for this regression was no longer significant when the effects of the inbreeding of the dam and the size of the litter were held constant. Again selection for total weaning weight has been some

TABLE 3. WITHIN GROUP SIMPLE AND PARTIAL REGRESSIONS:—INBREEDING OF DAM (b), INBREEDING OF LITTER (c), NUMBER OF PIGS BORN ALIVE (d), SURVIVAL (g, *transformed value in degrees*), AVERAGE BIRTH WEIGHT PER PIG IN EACH LITTER (h), AND TOTAL 56-DAY WEIGHT OF LITTER (i) (THE UNIT INCREASE OR DECREASE IN INBREEDING IS 1.00 OR 100 PERCENT)

Simple regressions		Partial regressions		Partial regressions		Partial regressions	
i/b	− 98.35	i/b.c	− 57.71	i/b.d	−33.17	i/b.cd	− 8.44
i/c	−155.12*	i/c.b	−131.14	i/c.d	−84.49	i/c.bd	−81.04
i/d	15.64**	i/d.b	15.57**	i/d.c	15.49**	i/d.cb	15.48**
		i/d.g	19.49**	i/d.h	18.54**	i/d.gh	20.26**
i/g	1.97**	i/g.d	2.32**	i/g.h	2.07**	i/g.dh	2.24**
i/h	18.41**	i/h.d	51.02**	i/h.g	−16.93**	i/h.dg	15.90**

* Significant at 5% level.
** Significant at 1% level.

what effective, but not to the same extent as that for survival, since the depressing effects of the inbreeding of the dam have not been as great as those of the inbreeding of the litter. The reasons for this are probably the same as were discussed in regard to the relationships between inbreeding and survival. However, there was a trend for some depressing effect of inbreeding on total litter weight at weaning.

The simple and partial regressions of total weaning weight of the litter on size of litter at birth are all positive and highly significant; and in this study, there was 20.26 pounds increase in the total 56 day weight of the litter for each additional live pig at birth when the effects of survival and birth weight were eliminated. This relationship is to be expected if there was little association between litter size and average weaning weight as reported by other workers.

An increase in survival increased total weaning weight of the litter. These

regressions were highly significant and changed very little when the effects of size of litter and birth weight were eliminated.

Total weaning weight of the litter was increased 15.9 pounds with an increase of one pound in the average birth weight when size of litter and survival are held constant. However, when only the effects of survival were eliminated an increase of one pound in the average birth weight decreased the total weaning weight 16.9 pounds. This last regression is difficult to interpret in relation to the others; but it is probably due to the fact that the heavier pigs at birth were in the smaller litters since there was a significant negative regression of average birth weight on litter size (coef. $= -.057$). When size of litter at birth was the only other factor held constant the regression of total weaning weight on average birth weight was very large ($i/d.h = 51.02$) indicating a very strong influence due to birth weight alone.

It is apparent in both phases of this study that, so far as the offspring themselves are concerned, birth weight had the greatest effect upon both survival and total weaning weight of the litter. This fact and the one that there was a strong relationship between survival and total weaning weight indicate that, with the pigs farrowed during the course of the project so far, vitality and growth impulse were apparently interrelated and both were capable of being expressed during prenatal development as well as after birth. This physiological relationship may be explained further as such.

The basis for vitality has been established at a very early stage in each pig's development—probably at the time of fertilization for undoubtedly it is genetic in origin. Vitality or vigor is then manifested in one respect by greater growth and physiological development during the embryonic and fetal periods and finally results in the birth of a heavier pig which has the ability to continue to be vigorous and grow rapidly during the nursing period if the proper environment is provided. The results of the above study would indicate that the basic causes for growth impulse and vitality are certainly closely associated or the same. It need be taken into account, however, that there are a number of complicating effects, such as uterine environment (including size of the litter and position in-utero) and environmental conditions after birth, which will alter this relationship considerably in some instances even though a good basis for growth and survival has already been established.

The authors fully realize that the data presented are somewhat biased inasmuch as they represent a highly selected population in which only the most vigorous individuals were saved for breeders. Nevertheless, the relationships between the factors studied are descriptive of the inbred lines of swine being developed in the Minnesota swine breeding project. Some of the results, especially the effects of inbreeding on vigor, are not what would be expected

on the basis of most previous inbreeding experiments in swine.

The effects of inbreeding on vigor are interesting and significant in this study since there was not a rapid decline in vigor as inbreeding progressed when using a flexible system and rigid selection. In the case of survival there was practically no decline. Miss King (1918, 1919) actually improved the fertility and size in rats by selection even when using a fixed and rapid system of inbreeding. Therefore, these results, too, are encouraging for they demonstrate the possibility of maintaining many of the elements of vigor when developing inbred lines of livestock with the genetic purity so desirable in breeding animals.

Summary and Conclusions

Data from 745 gilt litters composed of 5562 pigs born alive and of which 3918 pigs survived to weaning were utilized to study the effects of inbreeding, size of litter, and birth weight upon survival and total weaning weight of the litter. These litters included 12 Poland China inbred lines, one Minnesota No. 1 line, one Minnesota No. 2 line, and eight miscellaneous line-crosses.

Neither the inbreeding of the dam nor the inbreeding of the litter had a significant effect upon survival of the pigs from birth to weaning or upon the total weaning weight of the litter.

With the hogs used in this study, it has been shown that selection has been effective in holding survival at a relatively high level for inbred stock in spite of the depressing effects generally associated with inbreeding. Selection was also somewhat effective insofar as total litter weaning weight is concerned but not to as great an extent as for survival.

An increase in the size of the litter at birth reduced the chances for survival; the effects, however, were small. An increase of one pig in the size of litter increased the total weaning weight of the litter on the average by 20.26 pounds, when birth weight and survival were held constant.

Average birth weight of the litter had the greatest effect upon both survival and total weaning weight of the litter. An increase of one pound in average birth weight increased total weaning weight 15.9 pounds.

An increase in survival increased the total weaning weight of the litter.

The analysis of these data indicates a strong interrelationship between vitality and growth impulse both of which were capable of being expressed before birth as well as afterwards. However, the maternal influence has not been separated.

Literature Cited

Bywaters, J. H. 1937. The Hereditary and Environmental Portions of Variance in Weaning Weights of Poland China Pigs. Genetics. 22: 457–468.

Clark, A. and W. H. Leonard. 1939. The Analysis of Variance with Special Reference to Data Expressed as Percentages. Jour. Amer. Soc. Agron. 31: 55–66.

Cummings, J. N., L. M. Winters and H. A. Stewart. 1946. The Heritability of Some Factors Affecting Productivity of Brood Sows. (Unpublished data.)

Donald, H. P. 1937. The Milk Consumption and Growth of Suckling Pigs. Empire Jour. Exp. Agric., 5: 349–360.

Donald, H. P. 1939. The Relative Importance of Sow and Litter During the Growth of Suckling Pigs: A Comparison of Fostered with Normally Reared Pigs. Empire Jour. Exp. Agric., 7: 32–41.

Hetzer, H. O., W. V. Lambert and J. H. Zeller. 1940. Influence of Inbreeding and Other Factors on Litter Size in Chester White Swine. U. S. Dept. Agric. Cir. 570.

Hodgson, R. E. 1935. An Eight Generation Experiment in Inbreeding Swine. Jour. Hered. 26: 209–217.

Kernkamp, H. C. H. 1946. A Study of Losses in Baby Pigs. (Unpublished)

Kernkamp, H. C. H. 1943. Pig Mortality. Ann. Meet. U. S. Livestock Sanitary Assoc., Proc., 47: 87–89.

King, Helen D. 1918 and 1919. Studies on Inbreeding. Jour. Exp. Zool. 26: 1–54; 26: 335–378; 27: 1–35; 29: 71–102.

Lush, J. L., A. L. Anderson, C. C. Culbertson and W. E. Hammond. 1933. The Reliability of Some Measures of Productiveness of Individual Brood Sows. Amer. Soc. Anim. Prod., Proc., pp. 282–287.

Lush, J. L. and C. C. Culbertson. 1931. The Consequences of Inbreeding Poland China Hogs. Iowa Agric. Sta. Ann. Rpt., p. 23.

Lush, J. L. and A. E. Molln. 1942. Litter Size and Weight as Permanent Characteristics of Sows. U. S. Dept. of Agric. Tech. Bul. 836. 40 pp.

Lüthge, H. 1933. Beobachtungen über Bedeutung der Ausgleichenheit von Ferkelwurfen und die Vererbung dieser Eigenschaft. Züchtungskunde, 8: 333–344.

McPhee, H. C., E. Z. Russel and John Zeller. 1931. An Inbreeding Experiment with Poland China Swine. Jour. Hered. 22: 393–403.

Menzies-Kitchin, A. W. 1937. Fertility, Mortality, and Growth Rate in Pigs. Jour. Agric. Sci., 27: 611–625.

Meyer, Walter. 1940. Die Aufzuchtverluste beim Schwein. Jour. für Landwirtschaft. 87: 302–308.

Olbrycht, T. M. 1943. The Statistical Basis of Selection in Animal Husbandry. Jour. Agr. Sci. 33: 28–43, 74–84.

Smith, A. D. B. and H. P. Donald. 1937. Weaning Weight of Pigs and Litter Sampling with Reference to Litter Size. Jour. Agric. Sci. 27: 485–502.

Snedecor, G. W. 1940. Statistical Methods Applied to Experiments in Agriculture and Biology. Ed. 3. Ia. State Collegiate Press, Inc., Ames, Iowa.

Weaver, L. A. and Ralph Bogart. 1943. Some Factors Influencing Efficient Production of Sows. Mo. Agric. Expt. Sta. Bul. 461.

Willham, O. S. and W. A. Craft. 1939. An Experimental Study of Inbreeding and Outbreeding Swine. Okla. Agric. Expt. Sta. Tech. Bul. 7.

Winters, L. M., R. E. Comstock and D. L. Dailey. 1943. The Development of An Inbred Line of Swine (Minn. No. 1) From a Crossbred Foundation. JOURNAL OF ANIMAL SCIENCE, 2: 129–137.

Winters, L. M., R. E. Comstock, R. E. Hodgson, O. M. Kiser, P. S. Jordan and D. L. Dailey. 1943. Experiments with Inbreeding Swine and Sheep. Minn. Agric. Expt. Sta. Bul. 364.

Wright, S. 1922. The Effects of Inbreeding and Crossbreeding on Guinea Pigs. U. S. Dept. Agric. Bul. 1090.

Wright, S. 1922a. The Effects of Inbreeding and Crossbreeding on Guinea Pigs. U. S. Dept. Agric. Bul. 1121.

Wright, S. 1922b. Coefficients of Inbreeding and Relationship. Amer. Nat. 56: 330–338.

Zeller, J. H., T. G. Johnson and W. A. Craft. 1937. The Significance of Weight Changes in Sows During the Gestation and Suckling Periods. Amer. Soc. Anim. Prod., pp. 121–126.

THE HERITABILITY OF SOME FACTORS AFFECTING PRODUCTIVITY OF BROOD SOWS[1]

J. N. Cummings, L. M. Winters and H. A. Stewart[2]
University of Minnesota

THE RATE of improvement in livestock through selection depends upon the variation of the characteristic among the population, the proportion of each generation required for replacement, and the heritability of the characteristic or character. In the past many workers have devised different methods of determining "heritabilities" or estimates of the degree of inheritance of quantitative characters. These estimates measure the portion of the observed variance which is caused by differences in heredity or the degree to which quantitative characteristics are transmitted from parent to offspring. In doing this, as was first demonstrated by Wright (1920), one divides the total variation into that portion due to environmental causes and that due to genetic causes affected by additive genes.

The inheritance of quantitative characters is based largely upon the multiple factor hypothesis which deals with the effects of additive genes. However, one should not ignore the fact that gene interaction, epistasis, and dominance are factors which likely play a role in the expression of these characters through inheritance. The latter causes are included in most heritability estimates only to a small degree depending upon the method of determination.

There has been considerable variation in the heritability estimates already reported on various factors involved in the productivity of brood sows. Still more variation between these estimates can be expected as more of them are determined, because each one depends upon the genotypes in the particular population, the size of the population, and the environment under which the population is maintained. Most reports so far have, however, indicated a lack of wide variation in heritability estimates for measures on sow productivity during the preweaning period.

Lush *et al.* (1934) found that 6 percent of the variance in birth weights of pigs was due to heredity of the pigs. Stewart (1945) found that heritability of litter size at birth was approximately 17 percent. But, he also reported

[1] Paper No. 2326, Scientific Journal Series of the Minnesota Agricultural Experiment Station in cooperation with the Regional Swine Breeding Laboratory, Ames, Iowa, Bureau of Animal Industry, U. S. Department of Agriculture. Funds for the statistical analyses of this study were provided in part by a Grant in Aid of Research of the Graduate School, University of Minn.

[2] H. A. Stewart is Professor in the Department of Animal Industry, North Carolina State College. The authors are indebted to Mrs. Helen Feldman for her assistance in making many of the statistical calculations included in this paper.

that heritability estimates for the same factor ranged from 10 to 44 percent as found by other workers.

Size of litter at weaning was found by Lush and Molln (1942), Hetzer *et al.* (1940), and by Olbrycht (1943) to be between 17 and 20 percent heritable. Lush and Culbertson (1936) and Bywaters (1937) found that the heritability of weaning weights of individual pigs was between 15 and 20 percent, and 18 percent was reported by Lush and Molln (1942) as an estimate of the heritability of the total weaning weight of the litter.

The purpose of this study was to obtain further information on the heritability of factors affecting the productivity of brood sows during the pre-weaning period. The factors studied were: (1) survival up to weaning time of the pigs born alive, (2) size of litter at birth, (3) total litter weight at birth, (4) size of litter at weaning, and (5) total weaning weight of the litter.

Materials and Methods

The data used were taken from the farrowing and pre-weaning records of the sows farrowing in the Minnesota swine breeding project and maintained at five of the sub-stations of the Minnesota Agricultural Experiment Station. These hogs included the various inbred lines and cross-lines of Poland China and two inbred lines from crossbred foundations (Minn. No. 1 and Minn. No. 2). The factors studied were determined from these records as follows:

(1) Survival; determined by the ratio (in percentage) of the number of pigs alive at weaning to the number born alive in each litter.
(2) Size of litter at birth; the number of pigs born alive in each litter.
(3) Total litter weight at birth; total weight of all pigs born alive in each litter.
(4) Size of litter at weaning; the number of pigs alive in each litter at the time of weaning.
(5) Total weaning weight of the litter; the total weight of all pigs in each litter at the time they were weaned.

All pigs were weaned when they were 56 days old. The methods of breeding, feeding, management, and the keeping of records are described elsewhere (Winters *et al.*, 1943).

The heritability of each factor was determined by doubling the intra-sire regression of the daughter's record on the dam's record. According to Lush and Straus (1942), this method is the most dependable in estimating heritability in data where the sire cannot express the characteristic himself, where the dams are likely to be more highly selected than the daughters, and especially where there is likely to be any chance for a difference in en-

vironment between different herds or the sire groups. Lush (1940) states that the amount of genetic variance accounted for by this method includes: (1) all of the effects due to additive genes, (2) about one-half of the effects due to interaction and epistasis, and (3) practically none, but maybe up to one-fourth, of the effects due to dominance.

The data used were from the 1938–1944 farrowing records of the first litters of 532 gilts of which there were 279 different dams. The reason for the difference in the number of daughters and dams is because in many cases two or more daughters out of the same dam were kept for breeding. Again, only the records on the first litters of the dams were used and in both cases included only those litters farrowed in the spring. In the analysis, both the daughters and their dams were grouped in such a way that each group contained only the daughters by the same sire that farrowed their first litters during the same seaon and at the same station. All dams mated to the same sire were farrowed at the same station during the same season and farrowed their first litters at the same station during the same season. Instead of taking the average of the gilts' records for each dam, they were considered separately and the dam's record was repeated for each daughter she had in that particular sire group. Thus, there were altogether 532 dam-daughter comparisons and 91 different sire groups.

The values for survival were transformed from percentage to angles expressed as degrees, where:

$$\text{angle} = \text{arc sine}\sqrt{\text{percentage}}.$$

These transformations are given in table form by Snedecor (1940) and the advantages and reasons for using transformed values instead of actual percentages are discussed by him and by Clark and Leonard (1939).

The regression for each factor studied was calculated from the intra-year, intra-station, intra-line, and intra-sire variance and covariance of the analysis of covariance.

Results and Discussion

Table 1 includes the average values of all the factors studied by station and line groups for the dams and daughters used.

The differences between the dams' and daughters' records are fairly large in favor of the dams. This is the result of selecting breeding stock from high performing litters.

As mentioned above, the heritability estimates were calculated by doubling the intra-sire regressions of daughter on dam. It is assumed that as inbreeding increases the characters become more fixed in the population and there will be less genetic variation. The average inbreeding coefficient for the

TABLE 1. MEAN VALUES FOR SURVIVAL (*a*), SIZE OF LITTER AT BIRTH (*b*), TOTAL LITTER WEIGHT AT BIRTH (*c*), SIZE OF LITTER AT WEANING (*d*), AND TOTAL WEANING WEIGHT OF THE LITTER (*e*)

Station	Breed	Line	Average for first litters of dams						Average for first litters of daughters						No. of sire groups
			No. of dams	*a* (%)	*b* (No. pigs)	*c* (Lbs.)	*d* (No. pigs)	*e* (Lbs.)	No. of daughters	*a* (%)	*b* (No. pigs)	*c* (Lbs.)	*d* (No. pigs)	*e* Lbs.)	
Central	P. Ch.	All	27	81.6	7.63	20.45	6.22	193.74	59	69.4	6.03	16.48	4.19	109.47	9
W. C.	P. Ch.	All	68	84.7	8.63	25.43	7.31	241.54	115	79.2	7.81	22.68	6.18	202.17	26
S. E.	P. Ch.	All	24	71.8	7.38	21.67	5.29	174.88	42	48.3	5.67	15.90	2.74	87.74	8
N. W.	P. Ch.	All	57	82.9	7.61	21.63	6.32	202.30	107	64.7	6.09	17.10	3.94	115.79	19
	Minn.	No. 2	19	83.3	7.89	22.08	6.48	178.63	36	53.7	8.64	21.41	4.64	123.69	4
N. C.	Minn.	No. 1	84	83.6	9.73	27.34	8.13	258.11	173	69.6	8.76	24.13	6.10	182.58	25
Totals			279	82.7	8.50	24.19	7.03	223.87	532	68.4	7.46	20.72	5.11	153.80	91

sows used in this study was 15.6 percent, therefore, the estimates of heritability were corrected in proportion to this amount of reduced variation.

The heritabilities for the factors studied along with their standard errors, which were calculated according to the method suggested by Hazel and Terrill (1945), are given in table 2. It will be noted that in determining the heritabilities of some of the factors, the effects due to other factors were eliminated. This was done by using partial regressions.

TABLE 2. ESTIMATES OF HERITABILITY OF SURVIVAL, SIZE OF LITTER AT BIRTH, TOTAL LITTER WEIGHT AT BIRTH, SIZE OF LITTER AT WEANING, AND TOTAL WEANING WEIGHT OF THE LITTER

Characteristic studied	Heritability (uncorrected for inbreeding)	Standard error for heritability	Heritability (corrected for inbreeding)
Survival	.349	±.170	.403
Survival, with effects of size of litter at birth, and total birth weight of litter eliminated.	.813		.939
Size of litter at birth	.188	±.135	.217
Total litter weight at birth	.307	±.122	.355
Total litter weight at birth, with effects of size of litter at birth eliminated	.343		.396
Size of litter at weaning	.274	±.155	.317
Size of litter at weaning with effects of size of litter at birth eliminated	.375		.434
Total weaning weight of litter	.064	±.139	.074
Total weaning weight of litter, with effects of size of litter at birth and survival eliminated	.506		.585

The estimate of heritability for survival in these pigs (40 percent) was the highest and that for total weaning weight of the litter (7 percent) was the lowest. Also, the error for the latter was proportionally the highest. The heritability estimate for survival, corrected for inbreeding, with the effects of size of litter at birth and birth weight eliminated, was very high (94 percent). This is probably due to the fact that there was such a close relationship between these two factors and survival, as reported by the authors in another paper (Winters *et al.*, 1946). But, for all practical purposes, the herit-

ability estimate determined by the simple regression is the more valuable one because it is subject to less error. A similar situation is found with that of total weaning weight of the litter.

It is interesting to note that the estimate of heritability for size of litter at weaning (32 percent) fell about midway between those for size of litter at birth (22 percent) and survival. This is to be expected and offers a check on the methods of determination. A similar check on the heritability of survival is found in the estimate obtained for size of litter at weaning with the effects of size of litter at birth eliminated (43 percent).

The heritability of total weaning weight of the litter, when the influence of size of litter at birth and survival are held constant (59 percent) could serve for all practical purposes and in a relative degree as a good estimate of heritability for milk production in the sows used in this study. The amount of extra feed consumed by the little pigs and their efficiency of feed utilization would contribute to their total weaned weight but will not invalidate this assumption unless greater milk productivity is directly associated with feed intake and utilization. That there are differences between sows of the same fertility in relation to their milk producing ability and that it affects the growth of the pigs has been shown in the work by Donald (1937, 1939) and by Zeller *et al.* (1937).

The regression coefficients from which the estimates of heritability for survival and for total litter weight at birth were determined, are significantly different from zero. The daughter-dam regressions for the other three factors studied are not statistically significant, but the ones for size of litter at weaning and for size of litter at birth are close enough to the fiducial limits usually set when calculating significance to give sufficient confidence that they are not largely due to sampling errors.

In many respects the heritability estimates reported in this study are different from those reported by other workers; and, with the exception of total weaning weight of the litter, they are higher. This does not mean that these estimates, as well as the others reported, have lost their significance, nor does it mean that each one as it stands does not have a definite practical application. Since estimates of heritability are affected by the proportion of the total variation that is due to environment, it is logical to conclude that these estimates may vary greatly between populations under different environmental conditions. As more heritabilities are determined from different herds, and as more data are evaluated, the greater will be the general application of the heritability estimate for each factor. For the present, however, each estimate of heritability has a definite value in describing the population from which it was determined and affords that particular worker another tool by means of which, if properly applied, additional improvement can be made

through selection. Sweeping deductions cannot be made from studies like this one until a number of similar studies but on different populations have been made.

A good example which may be used for the above reasoning lies in the heritability figure for size of litter at birth (22 percent) as reported in this study. Stewart (1945) reported a heritability of 17 percent (15 percent uncorrected for inbreeding and determined by intra-sire regression) for the same factor when using many of the same data included in this report. By including additional data from litters farrowed after he made his study, this figure has been increased to 22 percent. The main point is that a somewhat different population has been analyzed or environmental conditions have been so altered as to change the hereditary portion of the variance.

Summary and Conclusions

Heritabilities of five factors affecting productivity of brood sows during the pre-weaning period and used in the Minnesota swine breeding project have been reported in the above study. Each was determined by doubling the intra-sire regression of the daughter's record on the dam's record using data from the farrowing and pre-weaning records on the first litters of gilts from 1938 to 1944 inclusive. Altogether, 532 daughter-dam comparisons were included.

The heritability estimates as determined by this study were as follows: (1) Survival from birth to weaning, 40 percent; (2) size of litter at birth, 22 percent; (3) total litter weight at birth, 36 percent; (4) size of litter at weaning, 32 percent; and (5) total weaning weight of the litter, 7 percent.

The estimate of heritability for the total weaning weight of the litter, with effects of size of litter at birth and survival held constant, was found to be 59 percent. It is suggested that this estimate might be a close approximation for that of milk production in the sows bred and farrowed at the Minnesota stations.

It is also pointed out that these estimates of heritability, as well as many others already reported should be applied mainly as descriptions of the populations from which they were derived. These descriptions may be used advantageously as guides to further improvement through selection within the particular herds or lines, or in populations under similar environmental conditions.

Literature Cited

Bywaters, J. H. 1937. The Hereditary and Environmental Portion of Variance in Weaning Weights of Poland China Pigs. Genetics, 22: 457–468.

Clark, A. and W. H. Leonard. 1939. The Analysis of Variance with Special Reference to Data Expressed As Percentages. Jour. Amer. Soc. Agron., 31: 56–66.

Donald, H. P. 1937. The Milk Consumption and Growth of Suckling Pigs. Empire Jour. Exp. Agric., 5: 349–360.

Donald, H. P. 1939. The Relative Importance of Sow and Litter During the Growth of Suckling Pigs: A Comparison of Fostered with Normally Reared Pigs. Empire Jour. Exp. Agric., 7: 32–41.

Hazel, L. N. and C. E. Terrill. 1945. The Heritability of Weaning Weight and Staple Length in Range Rambouillet Lambs. JOURNAL OF ANIMAL SCIENCE, 4: 347–358.

Hetzer, H. O., W. V. Lambert and J. H. Zeller. 1940. Influence of Inbreeding and Other Factors on Litter Size in Chester White Swine. U. S. Dept. Agric. Cir. 570, 10 pp.

Lush. J. L. 1940. Intra-sire Correlations or Regressions of Offspring on Dam As a Method of Estimating Heritability of Characteristics. Amer. Soc. An. Prod., Proc., pp. 293–301.

Lush, J. L. and C. C. Culbertson. 1936. The Consequences of Inbreeding Poland China Hogs. Iowa Agric. Expt. St. Ann. Rpt., p. 72.

Lush, J. L., H. O. Hetzer and C. C. Culbertson. 1934. Factors Affecting Birth Weights of Swine. Genetics, 19: 329–334.

Lush, J. L. and A. E. Molln. 1942. Litter Size and Weight As Permanent Characteristics of Sows. U. S. Dept. Agric. Tech. Bul. 836, 40 pp.

Lush, J. L. and F. S. Straus. 1942. The Heritability of Butterfat Production in Dairy Cattle. Jour. Dairy Sci. 25: 975–982.

Olbrycht, T. M. 1943. The Statistical Basis of Selection in Animal Husbandry. Jour. Agric. Sci. 33: 28–43, 74–84.

Snedecor, G. W. 1940. Statistical Methods Applied to Experiments in Agriculture and Biology. Ed. 3 Ia. State Coll. Press, Ames, Iowa.

Stewart, H. A. 1945. The Inheritance of Prolificacy in Swine. JOURNAL OF ANIMAL SCIENCE, 4: 359–366.

Winters, L. M., R. E. Comstock, R. E. Hodgson, O. M. Kiser, P. S. Jordan and D. L. Dailey. 1943. Experiments with Inbreeding Swine and Sheep. Minn. Agric. Exp. Sta. Bul. 364.

Winters, L. M., J. N. Cummings and H. A. Stewart. 1946. A Study of Factors Affecting Survival from Birth to Weaning and Total Weaning Weight of the Litter in Swine. Journal of Animal Science, 6: 288–296.

Wright, S. 1920. The Relative Importance of Heredity and Environment in Determining the Piebald Pattern of Guinea Pigs. Nat'l. Acad. Sci., Proc., 6: 320–332.

Zeller, J. H., T. G. Johnson and W. A. Craft. 1937. The Significance of Weight Changes in Sows During the Gestation and Suckling Periods. Amer. Soc. Anim. Prod., Proc., pp. 121–126.

THE EFFECT OF THIOURACIL ON EFFICIENCY OF GAINS AND CARCASS QUALITY IN SWINE[1]

W. N. McMillen, E. P. Reineke, L. J. Bratzler and M. J. Francis
Michigan Agricultural Experiment Station

THE recent discovery of a series of drugs that will inhibit the formation of thyroid hormone by the thyroid gland makes it possible, by administering such compounds, to determine the influence of subnormal levels of thyroidal activity on growth, fattening and carcass quality in various classes of livestock. Of the numerous compounds showing antithyroid properties, (Astwood, *et al.* 1943; Astwood, 1943; and others) thiouracil seems to be one of the most suitable for this purpose because of its high potency and low toxicity.

Kempster and Turner (1945) reported that when 0.2 percent thiouracil was fed to New Hampshire chicks for periods of 16 and 32 days beginning at 10 weeks of age the market grade was improved. In chicks fed thouracil from 6 to 14 weeks of age at levels of 0.025 to 0.2 percent growth was retarded slightly, but market grade and fat deposition were significantly improved (Andrews and Schnetzler, 1945). An increase in the rate of gain and a decrease in the feed required per unit of gain in older cockerels fed thiouracil was reported by Mixner, Tower and Upp (1946). Glazener and Jull (1946) reported that in chicks started on thiouracil at 2 weeks of age growth and efficiency of gains were depressed and the fleshing was inferior.

Muhrer and Hogan (1945) compared the gains and degree of fattening of hogs fed 0.2 percent thiouracil with that of pair-fed controls whose daily feed intake was restricted to that of the experimental group. It was reported that swine fed thiouracil for 28 days under these conditions were shorter and fatter than the controls and that they gained weight more rapidly and economically. However, use of the paired feeding system in this type of experiment tends to penalize the normal controls since their gains are necessarily depressed by limitation of their feed intake to that of the hypothyroid animals. Consequently it seemed desirable to test the effect of thiouracil on swine fed ad libitum. It also seemed of considerable interest to obtain more objective measurements on the effects obtained on growth and carcass quality than were available from the prior report.

Experimental Procedure

Ten Chester White barrows with an average body weight of 162 pounds were allotted into two groups of five pigs (lots 1 and 2). Ten Yorkshires aver-

[1] Paper No. 854 (n.s.), Scientific Journal Series of the Michigan Agricultural Experiment Station. Sponsored by the Institute of Nutrition with the Departments of Animal Husbandry, Physiology and Pharmacology, and State Prison of Southern Michigan cooperating.

aging 137 pounds were divided into two groups, including two barrows and three gilts in each (lots 3 and 4).

All groups were self-fed for a period of 41 days from January 7 to February 17, 1946, on a ration composed of corn 76 parts, meat scraps (50% protein) 6 parts, soybean oil meal (44% protein) 6 parts, alfalfa meal 10 parts. The mineral mixture consisted of salt 32.3 percent, bonemeal 32.3 percent, limestone 32.3 percent, ferrous sulfate 2.5 percent, copper sulfate 0.2 percent, manganese sulfate 0.1 percent, zinc oxide 0.1 percent, cobalt sulfate 0.1 percent and potassium iodide 0.1 percent.

In addition, lots 1 and 3 received 0.1 percent of thiouracil[2] mixed with the above ration, lots 2 and 4 being retained as normal controls.

The pigs were weighed out on the afternoon of February 17, kept off feed overnight and dressed packer style at the Rosevale Packing Company, DeWitt, Michigan, on the next afternoon. Selected carcass measurements were taken according to the method of Hankins and Ellis (1934, pp. 258–259) as follows: length of body (3)[3]; hind leg (4); depth of body, combined measurements (5), (6), (7); thickness of back fat, average of measurements (8), (9); circumference of front leg (12); and shoulder width (13).

The hogs were weighed before and after slaughtering and the dressing percentage was calculated on the basis of the dressed chilled weight. Weights were taken of the four primal cuts (ham, loin, skinned shoulder, and side) and the primal cut yields were calculated on the basis of the chilled carcass weight. Planimeter tracings were made of the face of the loin end of the right ham of each carcass in order to determine the proportion of fat to lean meat.[4]

Another trial was started September 6, 1946, using nine crossbred Duroc Jersey × Hampshire × Poland China pigs per lot. The pigs were taken off rape pasture and self-fed a ration of 87 parts corn, 12.5 parts (50%) meat scrap, and 0.5 parts salt for 38 days. One group (lot 5) was fed 0.1 percent of thiouracil mixed with the feed and the other (lot 6) was fed only the control ration. The pigs were weighed out October 14, and the carcasses were weighed and measured as in the first trial. The thyroids were also obtained, dissected free of fat and weighed on an analytical balance.

Results and Discussion

The most noticeable effect of feeding thiouracil was the reduction in both the total feed consumption and the feed required per pound of gain (table 1). The thiouracil-fed Chester Whites made 0.16 pound less daily gain, but required 13.8 percent less feed per unit of gain than the controls. The Yorkshires receiving thiouracil made 0.09 pound less daily gain on 18.8 percent

[2] Supplied through the courtesy of Dr. Stanton Hardy, Lederle Laboratories, Inc., Pearl River, New York.

[3] Measurement number as given by Hankins and Ellis (1934).

[4] We are indebted to Dr. R. W. Luecke, Research Associate in Agricultural Chemistry, for making the planimeter tracings.

TABLE 1. THE EFFECT OF THIOURACIL ON FEED CONSUMPTION AND DAILY GAINS

Items compared	Lot 1, Chester White 0.1% thiouracil	Lot 2, Chester White, control	Lot 3, Yorkshire, 0.1% thiouracil	Lot 4, Yorkshire, control	Lot 5, crossbred, 0.1% thiouracil	Lot 6, crossbred, control
No. of pigs per lot	5	5	5	5	9	9
Av. initial weight, lb.	162.2	161.2	136.0	137.8	167.1	167.2
Av. final weight, lb.	258.8	264.4	219.8	222.4	219.6	233.6
Av. daily gain, lb.	1.84	2.01	1.59	1.68	1.39*	1.74*
Av. daily ration, lb.	6.53	8.28	6.11	7.89	6.14	8.48
Feed per 100 pounds gain, lb.	363.0	421.0	394.0	485.0	445.0	486.0
Percentage feed saved	13.8		18.8		8.4	

* Difference in daily gains between lots 5 and 6 highly significant.

less feed per unit of gain than their controls. The greater reduction in feed requirements of the thiouracil-fed Yorkshires is in accord with the idea that this breed has a more active thyroid than the Chester White and consequently would show a greater metabolic decline when the thyroid secretion is blocked. The crossbred pigs that were fed thiouracil made .35 pound less daily gain on 8.4 percent less feed. Several factors may have been responsible for the less efficient gains of the pigs that were fed thiouracil in September compared with those receiving thiouracil in the winter trials. It seems possible that the depressing effect of hot weather may have been more pronounced in the hypothyroid group. Secondly, the feeders were outside the barn, some distance from the sleeping quarters in the September trial whereas they were inside the barn in the winter trials. The somewhat lower protein content of the ration used in the last trial, together with a reduced appetite, may have resulted in the experimental group receiving a suboptimal level of protein.

Thyroid weights were obtained only in the last trial. The average weight of the thyroids from the thiouracil-fed pigs was 18.048 gm. compared to 7.639 gm. in the controls, a 2.36 fold increase. This compares favorably with the enlargement of the thyroids of rats under similar treatment (Reineke *et al.*, 1945) indicating that the level of thiouracil given was sufficient to produce a measurable antithyroid effect. Histologically the thyroids of the thiouracil-fed pigs showed pronounced hypertrophy and hyperplasia together with an absence of colloid similar to the findings previously reported in other species.

The pigs of all groups fed thiouracil began to show a tendency towards laziness by the end of the second week. They became very sluggish and slow to get up from their beds by the fourth week. At the end of the trial the thiouracil-fed pigs, especially the Chester Whites, fatigued easily when exer-

TABLE 2. THE EFFECT OF THIOURACIL ON CARCASS QUALITY

Items compared	Lot 1, Chester White, thiouracil	Lot 2, Chester White, control	Lot 3, Yorkshire, thiouracil	Lot 4, Yorkshire, control	Lot 5, Crossbred thiouracil	Lot 6, Crossbred, control
No. of carcasses	5	5	4	4	9	9
Dressing percentage*	73.7±0.37**	74.4±1.07	75.0±2.07	73.1±1.21	73.2±3.50	74.0±1.36
Length of body, cm.	77.8±1.47	79.5±2.45	78.7±2.05	79.6±3.33	75.5±1.95	78.5±1.64
Length of leg, cm.	51.5±1.12	52.8±0.73	50.3±1.71	50.6±1.88	53.1±1.74	53.3±1.33
Circumference of leg, cm.	14.3±0.34	14.6±0.66	14.4±0.24	14.5±0.05	14.5±0.49	14.7±0.48
Depth of body, cm.	37.3±1.20	37.1±3.10	33.4±0.89	33.9±2.01	38.0±0.69	39.2±1.32
Width of body, cm.	15.8±0.35	16.3±0.91	15.7±1.80	14.8±0.53	13.6±0.58	13.5±0.56
Back fat, cm.	6.1±0.80	6.4±0.39	5.0±0.44	5.0±0.20	4.7±0.48	5.0±0.51
Percentage of primal cuts	67.5±3.75	66.7±2.14	70.8±2.52	71.2±1.43		
Planimeter tracing, face of ham:						
Lean—percent	56.1±7.23	47.3±4.03	64.8±6.34	61.0±6.34		
Fat—percent	43.9±7.23	52.7±4.03	35.3±6.34	39.0±6.34		

* Chilled weight compared to live weight after 24 hour shrink.

** Standard deviation.

cised. The thiouracil-fed pigs in all groups lost some of their bloom and their hair coats were rougher than those on the controls.

The detailed carcass measurements (table 2) fail to show any significant differences between the fatness or proportion of fat to lean in the experimental groups and their controls. In fact the planimeter tracings of the ham faces indicate a tendency toward somewhat greater fatness in the controls of both groups in which tracings were made. The standard deviation of these figures is so high, however, as to render these differences insignificant. The thiouracil-fed lots show a small but insignificant decrease in length of body, and length and circumference of leg, indicating that the thiouracil treatment may have caused a slight retardation of skeletal growth.

The results differ from the earlier reports on fowls and the paper by Muhrer and Hogan (1945) on thiouracil fattening in swine in that no increase in fattening was observed although a considerable increase in economy of gains was recorded. The failure to observe an increase in fattening in our trials may be explained by the fact that the hogs employed had already reached a stage of maturity before the trial began where they would finish readily under normal feeding conditions.

It has been shown that thiourea (Mackenzie and Mackenzie, 1943) and thiouracil (Reineke, Mixner, and Turner, 1945; Barker, 1945) cause a decline in the metabolic rate which in turn would lower the maintenance requirements. Consequently greater gains per unit of feed could be expected. Evidence reported to date indicates that the desired growth must be obtained before thiouracil treatment is begun if favorable results are to be obtained.

Summary

The effect of thiouracil fed as .1 percent of the ration on economy of gains and carcass quality was studied with Chester White, Yorkshire and crossbred market pigs.

Compared with the controls, five Chester White barrows averaging 162 pounds and fed ad libitum for 41 days on a ration containing thiouracil made .16 pound less daily gain, but required 13.8 percent less feed per unit of gain. Five Yorkshire pigs given thiouracil for the same period averaged .09 pound less daily gain and required 18.8 percent less feed per unit of gain. Nine crossbred pigs fed thiouracil at a different season made .35 pound less daily gain and required 8.4 percent less feed per unit of gain than their controls.

All of the pigs in the experimental groups became lazy toward the end of the second week and became increasingly sluggish as the trial progressed. The greater increase in the economy of gain in the Yorkshires as compared to the Chester Whites is believed to be due to a higher natural thyroid secretion rate in the former and consequently a greater reduction in rate of metabolism under the influence of thiouracil. There were no significant differences in the carcasses attributable to the thiouracil treatment.

Literature Cited

Andrews, F. N. and E. E. Schnetzler. 1946. Influence of Thiouracil on Growth and Fattening in Broilers. Poultry Sci., 25: 124.

Astwood, E. B. 1943. The Chemical Nature of Compounds which Inhibit the Function of the Thyroid Gland. Jour. Pharmacol. and Exp. Therap., 78: 79.

Astwood, E. B., J. Sullivan, A. Bissell and R. Tyslowitz. 1943. Action of Certain Sulfonamides and of Thiourea on the Function of the Thyroid Gland of the Rat. Endocrinology, 32: 210.

Barker, S. B. 1945. Effects of Thyrotropin on Metabolism of Thiouracil Treated Rats. Endocrinology, 37: 230.

Glazener, E. W. and M. A. Jull. 1946. Effects of Thiouracil, Desiccated Thyroid and Stilbestrol Derivatives on Various Glands, Body Weight, and Dressing Appearance in the Chicken. Poultry Sci., 25: 236.

Hankins, O. G. and N. R. Ellis. 1934. Physical Characteristics of Hog Carcasses as Measures of Fatness. Jour. Agric. Research, 48: 257.

Kempster, H. L. and C. W. Turner. 1945. The Effect of Feeding Thiouracil on the Fleshing of New Hampshire Broilers. Poultry Sci., 24: 94.

Mackenzie, C. G. and Julia B. Mackenzie. 1943. Effect of Sulfonamides and Thiourea on the Thyroid Gland and on Basal Metabolism. Endocrinology, 32: 185.

Mixner, J. P., B. A. Tower and C. W. Upp. 1946. The Effect of Feeding Thiouracil on the Body Weight of New Hampshire Cockerels. Poultry Sci., 25: 536.

Muhrer, M. E. and A. Hogan. 1945. Effect of Thiouracil on Growing Swine. Proc. Soc. Exp. Biol. Med. 60: 211.

Reineke, E. P., J. P. Mixner and C. W. Turner. 1945. Effect of Graded Doses of Thyroxine on Metabolism and Thyroid Weight of Rats Treated with Thiouracil. Endocrinology, 36: 64.

NICOTINIC ACID DEFICIENCY AND NICOTINIC ACID REQUIREMENT OF YOUNG PIGS ON A PURIFIED DIET

W. C. Powick, N. R. Ellis, L. L. Madsen and C. N. Dale
United States Department of Agriculture

STUDIES designed to throw light on the possible relationship of nicotinic acid deficiency to the incidence of necrotic enteritis in swine have been in progress at the Agricultural Research Center at Beltsville, Maryland since 1941. The data thus far acquired, insofar as they relate to growth, symptoms, and gross pathology in nicotinic acid deficiency, to the nicotinic acid requirement of growing pigs. and to chemical examination of material from the experimental animals, are reported in this paper.

Procedures

Nine feeding experiments have been conducted with the following features in common. Thrifty young pigs, approximately three weeks old, were assigned to groups in such manner that each litter was represented in each group and that the groups were as nearly as possible equal in respect to weight and sex. All pigs received the same high-protein purified basal diet, practically devoid of nicotinic acid but supplemented with accessory factors to make it otherwise adequate. In each experiment, certain groups of animals received the basal diet supplemented with the accessory factors other than nicotinic acid, while other groups received the basal diet with the supplements, including nicotinic acid. Direct comparison of the performance of litter mates subjected to different treatments as well as comparison of the mean performance of the groups was therefore always possible.

The basal diet was composed of 25 parts of extracted casein, 59.5 parts of dextrin, 2 parts of agar, 10 parts of lard, and 3.5 parts of salt mixture. The salt mixture was prepared from 2,063.5 gm. of calcium carbonate, 1,614.0 gm. of dibasic calcium phosphate, 1,047.0 gm. of monobasic potassium phosphate, 330.0 gm. of potassium sulphate, 315.0 gm. of magnesium carbonate, 531.0 gm. of potassium carbonate, 525.0 gm. of sodium chloride, 77.5 gm. of ferric sulphate, 3.75 gm. of potassium iodide, 7.50 gm. of sodium fluoride, 15.00 gm. of manganese sulphate (1 H_2O) 15.00 gm. of sodium silicate (dry), 7.50 gm. of potassium alum (12 H_2O), and 7.50 gm. of copper sulphate (5 H_2O). The accessory vitamin factors other than nicotinic acid per kilogram live weight per week consisted of 0.7 mg. of thiamine hydrochloride, 1 mg. of riboflavin, 1 mg. of pyridoxine hydrochloride, 3.5 mg. of calcium pantothenate, 140 mg. of choline hydrochloride, 1.5 ml. of cod liver oil, and 7 mg. of alpha tocopherol.

Nicotinic acid was the sole variable in the diet. It was generally supplied to the appropriate groups at the rate of 5 mg. per kilogram live weight per day, but in experiments to determine the minimum requirement, additional groups were set up to receive 2 mg., 0.6 mg., 0.2 mg., 0.1 mg., and 0.05 mg. per kilogram live weight per day.

Except where symptoms of anorexia developed, the basal diet fed per day amounted to 4 percent of the last recorded weights of the animals, divided between two feedings. Before feeding, the dry diet was mixed with the accessory factors in solution and with warm water to the consistency of a purée. However, when there was reason to suppose that an appreciable portion of the ration might be left unconsumed, the full quantity of accessory factors was combined with a suitable portion of the basal ration in a preliminary feeding, to be followed by the remainder of the basal ration if the animals would consume it. In feeding the accessory factors, the practice was followed of supplying the B-vitamin factors and choline on Mondays, Wednesdays and Fridays, the cod liver oil on Tuesdays and Thursdays, and the alpha tocopherol on Fridays.

Except for the pigs in one experiment, only cholera susceptible pigs were employed. In all cases they were housed in a heated barn, and were held in pens that had been thoroughly cleaned and disinfected at the outset and that were washed thereafter at least three times a week. In some experiments the pigs were penned and fed individually in floor pens, in others they were penned and fed individually in raised wire cages to prevent accumulation of fecal material, while in the other experiments they were penned and fed collectively as groups in commodious floor pens. In all cases the pigs were observed daily for abnormal symptoms, except on Sundays and holidays, and were weighed at weekly intervals.

Results

Since the differences in procedure between the several experiments seem to have been without significance in their bearing upon the comparisons with which this paper is concerned, all the experiments will here be treated as one. An analysis of the results obtained has also shown the justification for including all pigs receiving 1 mg. or more of nicotinic acid per kilogram live weight per day in a single "normal" group, and of including pigs receiving 0.1 mg. and 0.05 mg. per kilogram live weight per day in a single deficient group along with pigs receiving no nicotinic acid. In the following discussion the principal comparisons will be made between the normal and deficient groups as thus constituted, under the headings of Growth, Symptoms, and Mortality and Gross Pathology.

Growth

Much emphasis has been placed upon the use of standardized animals for nutrition experiments, the variations in growth response among non-standardized animals of different weight, age, and litter being well recognized. No experimental plan can entirely remove the error occurring from the use of non-standardized animals. The effect of differences in initial weight, however, can be largely eliminated by expressing all weights, or gains, as percentages of the initial weight; and error due to inherent litter differences may be eliminated by restricting all comparisons to those between pigs of the same litter. A surprising degree of uniformity in growth response among pigs of the same litter subjected to the same treatment is then frequently observed. Accordingly the weekly gains of all pigs in these experiments were recalculated in this manner, and comparisons were set up between normal pigs and their deficient litter mates.

Restrictions of space forbid the reporting of the data in detail for individual pigs, and a summary of the data obtained after three weeks and after six weeks of experimental feeding must suffice.

The data for the third week cover 38 litters with 67 animals in the normal group and 85 animals in the deficient group. Of the normal animals, 43 received nicotinic acid at the level of 5 mg. per kilogram live weight per day, 12 at a level of 2½ mg., 6 at a level of 2 mg., and 6 at a level of 1 mg. Of the deficient animals, 65 received no nicotinic acid, 14 received 0.1 mg., and 6 received 0.05 mg. per kilogram live weight per day. Twenty-six litters had more than one representative each in the normal group, and 29 more than one each in the deficient group, permitting an estimate of variability within litter subclasses.

At the end of the third week the mean gain of the normal group was 54.9 percent of the initial weights and that of the deficient group was 43.6 percent. In 9 litters, however, represented by 12 pigs in the normal group and 14 pigs in the deficient group, the mean gain of the deficient pigs was greater than that of their normal litter mates.

The data for the sixth week cover the same 38 litters, with 62 pigs in the normal group and 80 in the deficient group, 5 pigs at the 5 mg. level having been removed, according to plan, from the normal group, and 5 pigs receiving no nicotinic acid having been removed from the deficient group. Twenty-three litters had more than one representative each in the normal group, and 27 more than one each in the deficient group.

At the end of the sixth week the mean gain for the normal group was 153.4 percent of the initial weights, and that of the deficient group was 75.7 percent. In 4 litters, represented by 5 normal and 6 deficient animals, the

mean gain of the deficient animals was greater than that of their normal litter mates.

The growth data for both the third and the sixth weeks were subjected to the analysis of variance, employing the method of "expected numbers" designed for disproportionate sub-classes as outlined by Snedecor and Cox (1935), with the results summarized in table 1.

TABLE 1. SUMMARY OF ANALYSIS OF GROWTH DATA FOR THIRD AND SIXTH WEEKS

Source of variance	Degrees of freedom	Mean square	*F* calculated from "error"	*F* calculated from "interaction"
Third week				
Between normal and deficient animals	1	6,685.02	32.16**	30.37**
Between litters	37	1,769.38	8.51**	8.04**
Interaction	37	220.10	1.06	—
Between litter mates on same treatment (error)	70	207.84	—	—
Sixth week				
Between normal and deficient animals	1	224,021.50	171.34**	94.54**
Between litters	37	6,123.15	4.68**	2.58**
Interaction	37	2,369.38	1.71*	—
Between litter mates on same treatment (error)	60	1,307.41	—	—

* Significant, $P = .05 - .01$.
** Highly significant, $P = .01$.

From this analysis it appears first of all that there was a highly significant difference in growth response between litters as compared with the differences in growth between litter mates receiving the same treatment. The impropriety of comparing the performance of a deficient pig from one litter with that of normal pigs from other litters is thus established.

Secondly, the mean retarding effect of nicotinic acid deficiency on growth is clearly evident and highly significant by the end of the third week of deficiency, and is greatly accentuated by the end of the sixth week. Notwithstanding the fact that a number of deficient pigs failed to show any retardation of growth, beyond question nicotinic acid was needed for normal growth by most of the pigs employed in these experiments.

Thirdly, by the end of the sixth week there was evident an appreciable variability between litters in respect to the magnitude of the growth impair-

ment of the deficient animals as compared with the corresponding variability between litter mates receiving the same treatment. This is reflected in the relative magnitudes of interaction and error.

Nicotinic Acid Requirement for Growing Pigs

In three experiments, additional groups of pigs were supplied with intermediate levels of nicotinic acid with a view to determining the minimum requirement for normal growth. In two of these experiments the levels employed were 5, 2, 0.6, 0.2, 0.1, and 0 mg. per kilogram live weight per day, while in the third the levels were 2.5, 1.0, 0.3, 0.1, 0.05 and 0 mg. In all, 84 pigs from 17 litters were used in these experiments.

For the first two experiments, the distribution of litter mates and their gains in weight at the end of six weeks of experimental feeding, expressed in terms of percentages of initial weights, are shown in table 2.

TABLE 2. GAIN PERCENT, MADE BY PIGS RECEIVING DIFFERENT LEVELS OF NICOTINIC ACID IN SIX WEEKS OF EXPERIMENTAL FEEDING

Litter No.	Gains by pigs receiving indicated number of milligrams of nicotinic acid per kilogram live weight per day:					
	5	2	0.6	0.2	0.1	0
160	91.8	90.0	135.7	99.1	51.8	76.1
167	97.6	114.7	39.7	71.6	75.6	61.9
203	63.9	—	78.6	—	36.6	—
205	—	80.6	—	31.6	—	5.6
212	164.7	117.4	158.5	105.9	158.4	163.4
284	74.1	97.5	61.4	71.9	79.1	79.3
300	105.3	—	—	—	120.2	95.9
296	—	128.5	104.4	96.1	—	—
344	92.8	—	—	—	79.2	36.6
306	—	90.4	96.6	110.3	—	—
313	164.6	152.1	120.5	135.5	94.9	115.5
Means	106.85	108.90	99.425	90.25	86.975	79.28

This table shows a progressive decrease in group performance the more the level of nicotinic acid fed is reduced below 2 mg. per kilogram live weight per day. Yet the reduction is not impressive as compared with the irregularities within individual litters; and statistical comparisons restricted to litter mates in any two groups show no significant group differences except for that between the 5 and 0 mg. levels. A more complete analysis of variance, utilizing all the data, however, discloses a highly significant difference in mean performance between the first three and the last three groups, and a

significant difference in mean performance between the first two and the last four groups. Unfortunately these comparisons, while indicating a real nicotinic acid effect, do not serve to indicate the most probable dividing line between adequacy and inadequacy. The original data, indeed, suggest that there may be no unique dividing line, but that the nicotinic acid requirement varies more or less from pig to pig, and that the average optimal amount for the pigs in these experiments was between 0.6 and 2.0 mg per kilogram live weight per day.

In the third experiment with intermediate levels, nicotinic acid was fed at the rate of 2.5, 1.0, 0.3, 0.1, 0.05 and 0 mg. per kilogram live weight per day. The distribution of litter mates among the several groups and their percentage gains in weight during six weeks of experimental feeding are shown in table 3.

TABLE 3. GAIN PERCENT, MADE BY PIGS RECEIVING DIFFERENT LEVELS OF NICOTINIC ACID IN SIX WEEKS OF EXPERIMENTAL FEEDING

Litter No.	Gains by pigs receiving indicated number of milligrams of nicotinic acid per kilogram live weight per day:					
	2.5	1.0	0.3	0.1	0.05	0
509	113.0	153.0	185.6	87.0	36.7	57.0
510	233.6	218.3	167.8	260.6	97.1	30.5
514	155.6	89.1	95.7	55.5	23.2	27.6
518	111.3	241.1	172.6	104.5	145.0	182.0
531	141.8	167.8	73.8	20.8	2.4	64.8
536	160.0	107.9	106.7	10.4	11.5	55.0
Means	152.55	162.87	133.70	89.8	52.65	69.48

This table shows a marked progressive decrease in group performance as the level of nicotinic acid is reduced from 1.0 to 0.05 mg. per kilogram live weight per day, with considerable irregularity within individual litters. To determine the significance of the group differences, the mean performance of each group was compared statistically with that of every other group, with the results shown in table 4.

While these comparisons do not utilize all the data in any single comparison, they do indicate that a real improvement in performance was obtained by feeding more than 0.1 mg. of nicotinic acid per kilogram live weight per day. In addition to the comparisons between paired groups as entered in table 4, there is also a highly significant difference of 79.1 per cent between the mean performance of groups A, B and C and that of groups D, E and F, and a significant difference of 46.0 per cent between the performance of

groups A and B and that of groups C and D. It is thus suggested that the optimal level lies decidedly above 0.1 mg. of nicotinic acid per kilogram live weight per day. It will be observed, however, that in the comparisons restricted to two groups, the differences between adjacent groups in all cases fall short of significance, thus suggesting that the increments of dosage were too small to exhibit the significance of their effects in an experiment of these dimensions. Probably again the best indication of the nicotinic acid requirement of these pigs is afforded by the original data, which again suggest that

TABLE 4. DIFFERENCES IN MEAN PERFORMANCE OF GROUPS RECEIVING DIFFERENT LEVELS OF NICOTINIC ACID FOR A PERIOD OF SIX WEEKS

Higher level	Lower level					
	(A) 2.5 mg.	(B) 1.0 mg.	(C) 0.3 mg.	(D) 0.1 mg.	(E) 0.05 mg.	(F) 0 mg.
2.5 mg. (A)	—	−10.3	18.8	62.7	99.9*	83.1
1.0 mg. (B)	—	—	29.2	73.1*	110.2**	93.4**
0.3 mg. (C)	—	—	—	43.9	81.0**	64.2*
0.1 mg. (D)	—	—	—	—	37.1	20.3
0.05 mg. (E)	—	—	—	—	—	−16.9
0.00 mg. (F)	—	—	—	—	—	—

* Difference significant, $P = .05 - .01$.
** Difference highly significant, $P = .01$.

the requirement may vary from pig to pig, and indicate that the amount required for optimal mean gain in this experiment lay between 0.3 and 1.0 mg. per kilogram live weight per day.

Combining the results of the three experiments, it is suggested that a level of between 0.6 and 1.0 mg. (probably nearer the 0.6 than the 1.0 mg. value) of nicotinic acid per kilogram live weight per day would be needed to promote optimal mean growth in the experimental animals. Yet because of the indications of variable requirement among pigs, and the limited number of pigs employed in these experiments, these estimates should not be viewed as recommendations for practical feeding, but simply as our judgment of the best estimates afforded by our data.

Symptoms

The impairment of growth of the nicotinic acid deficient pigs was generally accompanied by diarrhea, beginning at times as early as the third week of deficiency. There was also apt to be impairment of appetite, which became noticeable somewhat later. In the more severe cases, these symptoms were

accompanied by a general deterioration in the condition of the pig to the point of emaciation, extreme weakness and death. There were no noticeable neurological symptoms.

Throughout the experiments daily observations of the condition of pigs were made, with special attention to appetite and nature of the stools. Appetite was classed as "good" or "impaired," and stools as "formed" or "unformed," and the total number of observations of each type was counted and expressed as percentage of the total number of observations. Where pigs were fed collectively, of course, it was not always possible to determine how many individuals in the group were eating subnormally or how many were passing the unformed stools. In such cases all pigs of the group were assumed to be affected with the abnormal symptom. This practice was more unfavorable to the "normal" groups than to the "deficient" groups, since in the former, abnormal symptoms were more exceptional than in the latter. The frequency of symptoms as thus defined, beginning with the eighth day of feeding, is shown in table 5.

TABLE 5. EFFECT OF NICOTINIC ACID DEFICIENCY ON APPETITE AND NATURE OF STOOLS

Item	Normal group		Deficient group	
	No. of observations	Frequency, percent	No. of observations	Frequency, percent
Good appetite	2273	90.27	1239	40.67
Impaired appetite	246	9.73	1808	59.33
Formed stools	1948	77.36	1006	33.02
Unformed stools	570	22.64	2041	66.98

These data support the data on growth in showing the damaging effect of nicotinic acid deficiency under the conditions of these experiments. In general, also, the exceptional pigs that grew normally on the deficient diet were least affected in respect to appetite and nature of stool.

For the experiments in which graded doses of nicotinic acid were fed the corresponding data are reported in table 6.

These data indicate no derangement of appetite until the nicotinic acid intake fell below 0.3 mg. per kilogram live weight per day, though considerable diarrhea was evident among some of the pigs receiving as much as 1 mg. per kilogram live weight per day.

Mortality and Gross Pathology

Many of the animals employed in these experiments, after a preliminary feeding period of from 4 to 8, but mostly from 6 to 7 weeks, were used in a

TABLE 6. EFFECT OF NICOTINIC ACID LEVEL ON APPETITE AND NATURE OF STOOL

Items compared	Observations at levels of nicotinic acid feeding[1] indicated											
	5 mg.		2 mg.		0.6 mg.		0.2 mg.		0.1 mg.		0	
	Days	Frequency %	Days	Frequency %	Days	Frequency %	Days	Frequency %	Days	Frequency %	Days	Frequency %
Pigs from Litters Represented in Table 2												
Good appetite	230	89.5	233	90.3	221	87.6	211	82.7	196	75.6	192	78.0
Impaired appetite	27	10.5	25	9.7	33	12.4	44	17.3	60	24.4	54	22.0
Formed stools	224	87.2	233	91.0	224	87.2	203	79.0	186	72.1	187	75.1
Unformed stools	33	12.8	23	9.0	33	12.8	54	21.0	72	27.9	62	24.9
Pigs from Litters Represented in Table 3												
Nicotinic acid level[1]	2.5 mg.		1.0 mg.		0.3 mg.		0.1 mg.		0.05 mg.		0	
Good appetite	259	83.0	253	81.1	271	86.9	85	28.4	42	13.9	70	24.4
Impaired appetite	53	17.0	59	18.9	41	13.1	214	71.6	261	86.1	217	75.6
Formed stools	245	78.5	161	51.6	169	54.2	66	22.1	57	18.8	66	23.0
Unformed stools	67	21.5	151	48.4	143	45.8	233	77.9	246	81.2	221	77.0

[1] Levels are expressed on a per kilogram per day basis.

study of their reactions to artificial infection with *S. choleraesius*, and were no longer available for the strictly nutritional phase of our studies. The others remained on their previous regime to the end of the ninth week or in a few cases to the end of the twelfth week of the experiment.

The deaths are therefore based upon a population that was variable in respect to the length of the period during which they were available for observation, but that included all of the normal and deficient pigs employed in these experiments. Subject to this condition, a comparison of the mortality of the normal and deficient animals appears in table 7. Undoubtedly the mortality among the deficient animals would have been greater if all of the deficient animals, many of them in bad condition, had been retained to the end in this phase of the experiment.

At the end of the experiment, or on the occasion of prior death, all animals that remained in the nutritional phase of the experiment were subjected to

TABLE 7. MORTALITY AND OCCURRENCE OF NECROTIC LESIONS AS AFFECTED BY NICOTINIC ACID DEFICIENCY

Item	Normal group	Deficient group
Total no. of pigs observed	69	87
No. of deaths	1	18
Percent mortality	1.45	20.7
No. of pigs autopsied	28	50
No. of pigs showing necrotic lesions	1	37
Percent showing necrotic lesions	3.54	74.0

autopsy. The only lesions that occurred with sufficient frequency among the deficient animals to suggest a relationship to their prior feeding consisted of necrotic lesions on the inner walls of the cecum and colon. These varied greatly in extent and severity. In a few cases a diphtheritic membrane covered and practically occluded the whole of the large intestine; in about one fourth of the deficient animals lesions were entirely lacking; generally, the lesions when present were of slight to moderate severity. Table 7 shows the number and percentage of the normal and deficient animals subjected to autopsy that were affected with necrotic lesions, but does not show the extent or severity of these lesions through lack of a reliable system of grading.

Admittedly, in the phases of the experiment covered by table 7, the normal and deficient groups were no longer strictly comparable as to the periods covered by the mortality observations, or in the case of autopsy findings in respect to the litter represented. Nevertheless the difference between the two groups in respect to mortality rate and to incidence of necrotic lesions

is sufficiently striking to carry conviction that the difference is not a matter of chance.

While the specific factors entering into the production of the necrotic lesions may still have to be determined, it seems clear that in these experiments the lesions must be associated with nicotinic acid deficiency. It should be stressed, however, that the results of these experiments should not be interpreted as evidence that these lesions are produced by the same cause or causes as those lesions of the clinical disease commonly seen and recognized as necrotic enteritis. The conditions under which these tests have been carried out are after all highly artificial. Consequently unless similar results can be satisfactorily obtained under conditions that are natural, the occurrence of these necrotic lesions does not constitute a sound basis for evaluating the significance of a deficiency of nicotinic acid in the etiology of necrotic enteritis.

Chemical Observations

In an effort to obtain chemical evidence of nicotinic acid deficiency, a number of determinations of nicotinic acid in blood, urine, and livers of normal and deficient animals were made.

The cyanogen bromide reaction was employed exclusively, and the colors obtained were measured with the Coleman D. N. spectrophotometer. For the purpose of color development, metol in our hands appeared to be superior to p-aminoacetophenone in respect to the intensity and proportionality of the colors obtained. With due attention to details and after correcting for the color of the reagents, the transmittance of the color due to nicotinic acid for a wave length of 4000 Å was found to accord with Beer's law, to within the errors of measurement, for quantities of nicotinic acid ranging from 5 to 40 mcg.

In the preparation of urine samples for the nicotinic acid estimation, the method Perlzweig, Levy and Sarett (1940), employing acid hydrolysis, absorption with Lloyd's reagent, elution, and decolorization with lead nitrate and tribasic potassium phosphate was adopted. The same method, as adapted to solid material by Dann and Handler (1941), was employed for liver samples. For blood, the method of Klein, Perlzweig and Handler (1942) was employed, using a Folin-Wu blood filtrate prepared from whole oxalated blood. In all cases, the prepared solutions were adjusted to pH 4.5 with a glass electrode, before beginning the colorimetric estimation.

The blood samples were collected over oxalate from the tails of living animals, or from the hearts of animals killed for autopsy. The urine samples represented 24 hour specimens collected in special pens in which the urine passed through a fine mesh screen before being funneled into the containers.

In a few cases of nicotinic acid deficiency, where the animals were scouring, it was impossible to avoid serious contamination with colloidal fecal material. As fecal material from deficient animals has been found to contain considerable nicotinic acid, the high nicotinic acid content of these samples is probably due to the contamination. The liver samples were prepared from whole livers collected at autopsy, which were promptly weighed and prepared for analysis, analyses being begun the same day. Most of the results reported represented averages of satisfactory duplicate determinations. The results obtained with pertinent information respecting the source of the samples are listed in table 8.

The results show that the nicotinic acid tends to be somewhat lower in the blood and in the urine of animals receiving the purified diet without added nicotinic acid than in those of animals receiving a complete ration. There is however considerable variability in the nicotinic acid content of each material within each group of animals, and the determination of nicotinic acid in these fluids is evidently not a sure criterion of nicotinic acid deficiency. The high values obtained on urine samples contaminated with fecal material and miscellaneous determinations of nicotinic acid in feces, indicate that a considerable amount of unabsorbed nicotinic acid, presumably of bacterial origin, is present in the intestinal tract even during acute nicotinic acid deficiency. The results obtained in the examination of feces also showed no relation between the dietary regime or the physical state of the feces and their nicotinic acid content. These results are not reported because the data for calculating the nicotinic acid excreted per kilogram live weight per day are lacking. There is no evident difference between normal and deficient pigs in respect to the nicotinic acid content of their livers.

It appears paradoxical that in the presence of acute symptoms traceable only to nicotinic acid deficiency, the nicotinic acid content of blood, urine, and liver and probably of feces should be so largely maintained within normal limits.

Discussion

The question naturally arises as to the adequacy of the diet in respect to factors other than nicotinic acid. It did not include p-aminobenzoic acid, inositol or ascorbic acid, which are thus far not recognized as necessary for pigs. Neither did it contain biotin, folic acid or vitamin K; and like any "synthetic" diet it could be lacking in some as yet unknown factors that could occur in natural feeds. However, some of the animals receiving this ration with nicotinic acid added grew at a rate that equalled or even exceeded that expected of pigs under natural conditions, although the mean gain of our normal animals in a six week period was but 153 percent of their initial

TABLE 8. NICOTINIC ACID CONTENT OF BLOOD, URINE, AND LIVERS FROM EXPERIMENTAL ANIMALS

Whole blood samples			Urine samples				Liver samples	
					Nicotinic acid			
Pig no.	Day of experiment	Nicotinic acid, mcg. per c.c.	Pig no.	Day of experiment	Per c.c. mcg.	Per kilo live weight per day mg.	Pig no.	Nicotinic acid per gm. mcg.
Animals on Nicotinic Acid-Supplemented Rations								
7142	23	5.35	9587	7	1.48	.127	7884	138.0
7495	48	6.42	9587	14	0.74	.066	7769	142.2
7504	48	3.72	9587	21	1.77	.072	7763	203.6
7491	48	7.53	7884	25	0.67	.071	7788	164.0
7501	48	5.87	9587	35	1.26	.110	7784	137.0
7106	50	3.51	7142[1]	37	3.63	.907	7886	155.4
7057	55	5.95	7491[1]	37	1.19	.253		
7142	78	4.68	7501[1]	37	1.46	.285		
7495	92	6.52	7057[1]	40	1.22	.083		
7491	93	7.64	7491	43	0.52	.116		
			7501	43	1.65	.111		
			7106[1]	45	1.21	.229		
Mean		5.72			1.16	.036		156.7
Standard deviation		±1.35			±.47	±.023		±23.1
Animals on Nicotinic Acid-Deficient Rations								
7147	24	3.55	9588	7	0.83	.054	7761	138.2
7494	48	2.62	9588	14	0.73	.035	7770	150.9
7503	48	3.17	9588[2]	21	3.95	.095	7783	174.8
7492	48	4.31	7883	25	0.59	.020	7787	120.0
7502	48	4.93	9588[2]	35	5.82	.135	7888	161.3
7493	48	5.60	7495	36	0.53	.113	7883	146.7
7147	50	1.27	7502	36	0.42	.100	7762	165.1
7494	66	3.38	7502	38	0.54	.120	7768	157.2
7492	66	2.78	7492	38	0.36	.078	7786	145.3
7103	78	4.99	7147	38	0.00	.000	7882	153.7
7054	78	3.33	7054	40	0.00	.000	7885	124.4
			7103	41	0.00	.000		
			7496	46	0.77	.091		
			7503	46	0.87	.068		
			7762	67	0.39	.054		
			7885	67	1.72	.057		
Mean		3.63			.55	.056		148.9
Standard deviation		±1.19			±.43	±.040		±15.1

[1] The pig received nicotinic acid in at least one feeding during collection of sample. For purposes of comparison this is excluded from mean.

[2] Sample was heavily contaminated with fecal material and is excluded from mean.

weight, as compared with about 200 percent for pigs under natural conditions in the herds of this Bureau at Beltsville as calculated from data reported by Zeller and Hetzer (1944). In this connection, however, the adverse effect, on our experimental animals, of abrupt weaning at three weeks of age and the substitution of an unnatural feed for the sow's milk must be considered. Certainly our normal animals showed no evidence of nutritional deficiency.

Hughes (1943) reported experiments in which the minimum nicotinic acid requirement for pigs appeared to be between 5 and 10 mg. per 100 lb. live weight per day or between 0.11 and 0.22 mg. per kilogram live weight per day. This is decidedly less than the 0.6 to 1.0 mg. per kilogram live weight per day that seemed to be required for optimal growth in our experiments. To be sure, we have regarded this estimate as a statistical quantity derived from limited data and not as a nutritional constant, and we have noted the apparent variability between pigs as to their individual requirements. Apart from this it may be observed that the mean initial weight of the pigs employed by Hughes was 32.2 lbs. or 14.15 kg., whereas the average weight of our pigs in the experiments with graded doses was but 5.76 kg. at the start, and for those receiving adequate nicotinic acid, was but 12.95 kg. at the end of a six week feeding period. A recent publication by Braude, Kon, and White (1946) indicates that the nicotinic acid requirement decreases as pigs grow older and larger, but whether this tendency is operative at the ages now under consideration is not evident.

Wintrobe and associates (1945) report experiments which they interpret as indicating that only pigs receiving a low-protein diet are in need of nicotinic acid. This is at variance with the import of our results. From the evidence available, it is difficult to determine to what extent this difference is a matter of interpretation and to what extent it is real. In this connection, however, it should be noted (a) that Wintrobe's litter mates available for growth comparisons are too few to justify generalization, (b) that when the growth of his deficient animals on his high protein diet was compared with that of litter mates receiving nicotinic acid, the gains of the latter were decidedly superior if expressed in terms of percentage of initial weight, and (c) that in our experiments we have had exceptional animals on the deficient diet that grew normally and remained free of deficiency symptoms. We have not experimented with low-protein diets.

Summary

The effect on young pigs of the lack of dietary nicotinic acid and the optimal nicotinic acid level for growing pigs were studied in a series of feeding experiments involving 152 animals from 38 litters for the deficiency study and 84 pigs from 17 litters for the study of optimal level. Emphasis was placed on the use of litter mates for all comparisons, on the importance of adjusting growth data to allow for differences in initial weights, and on

the use of statistical methods, where applicable, in interpreting the significance of the results. Throughout the experiments the same high-protein ration consisting of purified ingredients including additions of purified accessory factors was employed. All animals not destined for use in subsequent studies were autopsied at the end of the experiment or on the occasion of their prior death.

The mean effect of absence of nicotinic acid from an otherwise adequate diet consisted in a highly significant depression of growth, a conspicuous impairment of appetite with high incidence of diarrhea, high mortality, and a high incidence of necrotic lesions of colon and cecum.

Occasional animals appeared to thrive with no nicotinic acid while other animals appeared to vary in their requirement.

The level of nicotinic acid required for optimal mean growth in our experiments appeared to be between 0.6 and 1.0 mg. per kilogram live weight per day for growing pigs between the age of 3 and 9 weeks.

Chemical studies failed to disclose a simple method for the diagnosis of nicotinic acid deficiency or to indicate the nature of the defect resulting therefrom.

Literature Cited

Braude, R., S. K. Kon and E. G. White. 1946. Observations on the Nicotinic Acid Requirements of Pigs. Biochem. Jour., 40: 843–855.

Dann, W. J. and Philip Handler. 1941. The Quantitative Estimation of Nicotinic Acid in Animal Tissues. Jour. Biol. Chem., 140: 201–213.

Hughes, E. H. 1943. The Minimum Requirement of Nicotinic Acid for the Growing Pig. JOURNAL OF ANIMAL SCIENCE, 2: 27–32.

Klein, J. Raymond, William A. Perlzweig and Philip Handler. 1942. Determination of Nicotinic Acid in Blood Cells and Plasma. Jour. Biol. Chem., 145: 27–34.

Perlzweig, William A., Edward D. Levy and Herbert P. Sarett. 1940. Nicotinic Acid Derivatives in Human Urine and Their Determination. Jour. Biol. Chem., 136: 729–745.

Snedecor, George W. and Gertrude M. Cox. 1935. Disproportionate Subclass Numbers in Tables of Multiple Classification. Ia. Agric. Exp. Sta., Res. Bul. 180: 235–272.

Wintrobe, Maxwell M., Harold J. Stein, R. H. Follis, Jr. and Stewart Humphreys. 1945. Nicotinic Acid and the Level of Protein Intake in the Nutrition of the Pig. Jour. Nutrition, 30: 395–412.

Zeller, J. H. and H. O. Hetzer. 1944. Influence of Type of Hog on Production Efficiency. U. S. Dept. Agric. Cir. 698, 16 pp.

THE COMPARATIVE VALUE OF A CAROTENE CONCENTRATE, ALFALFA MEAL, AND A FISH LIVER OIL IN MAINTAINING THE VITAMIN A CONTENT OF THE BLOOD AND LIVER OF FATTENING LAMBS[1]

J. A. Hoefer[2] and Willis D. Gallup
Oklahoma Agricultural Experiment Station[3]

IT HAS been widely reported in the literature that carotene from different sources varies in its biological value (Ward, 1940; Fraps and Meinke, Rubin and Bird, 1941; Smith and Otis, 1941; Jones *et al.* 1944). Since much of this work has been done with cattle, poultry, and small laboratory animals it has little direct application to sheep nutrition. If the efficiency of utilization of carotene and other vitamin A active substances by sheep is related to the source of these materials, it should become apparent in a comparison between such widely different sources as alfalfa meal, a natural source of carotene, a carotene concentrate prepared from carrots, and fish liver oil which supplies vitamin A *per se*. During the course of several experiments, designed to study factors which might influence the concentration of vitamins A and C in the blood plasma of lambs, it was possible to collect data on the storage of vitamin A in the livers of lambs which had received carotene from different sources and vitamin A from fish liver oil.

The results of Hauge *et al.* (1944) indicate that dairy cows can utilize carotene from alfalfa hay as well as isolated carotene. King and co-workers (1940) had previously reported however, that the carotene of alfalfa is more readily available to the bovine than crystalline carotene given in oil.

Rubin and Bird (1941) observed that a group of chicks fed alfalfa meal showed consistently larger stores of vitamin A than did other groups of chicks fed either crystalline carotene or vitamin A.

Guggenheim (1944) concluded from his work with rats that the utilization of carotene from various plant sources, or of carotene dissolved in different oils, varied according to the vitamin E content of these materials.

The investigations of Davies and Moore (1934) and of Gray, Hickman, and Brown (1940) indicate that vitamin A *per se* is utilized much more efficiently by the rat than carotene. Also Hilton and associates (1944) found that the carotene of dehydrated alfalfa hay was only about one-third as

[1] A part of the data presented herein was taken from a thesis presented by J. A. Hoefer to the Graduate School of Purdue University in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The senior author wishes to acknowledge the help and advice given by Dr. C. L. Shrewsbury, Mid-West Research Institute.

[2] Now on the Animal Husbandry Staff, Purdue University, Lafayette, Ind.

[3] Departments of Animal Husbandry and Agricultural Chemistry Research, Stillwater, Oklahoma.

efficient as vitamin A *per se* as a source of vitamin A in the rations of dairy cows for the production of milk fat of maximum vitamin A value. Record and associates (1937), however, were unable to find a difference between the absorption of carotene and of vitamin A by hens fed normal diets. Guilbert *et al.* (1937) make the statement that at low levels of intake, vitamin A and carotene approach biological equivalence but that the ratio of their respective efficiencies widens as the dosage is increased.

Various values have been reported for the carotene requirements of cattle depending upon the criterion used (Guilbert *et al.* 1937; Moore, 1939; Boyer *et al.* 1942; Keener *et al.* 1942; Moore, Berry and Sykes, 1943). Lewis and Wilson (1945) were able to maintain fair growth in calves on 32 units of vitamin A per kilogram of body weight. Blood levels and liver storage were low however, in all calves receiving up to 128 units.

Callison and Knowles (1944) have reported that no quantitatively measurable stores of vitamin A can be demonstrated in the livers of rats fed less than 50 to 80 units of vitamin A per kilogram of body weight per day, which is about four times the amount usually considered as the "minimum" requirement for the rat.

The generally accepted minimum carotene requirements of sheep for the prevention of night blindness (nyctolopia) are from 25 to 35 micrograms of carotene or from 6 to 8 micrograms of vitamin A per kilogram of body weight as suggested by Guilbert, Miller and Hughes (1937). Peirce (1945) has more recently reported, however, that the feeding of this minimum level brought about recovery in only one of three night-blind animals, whereas all animals which received from 50 to 55 micrograms of carotene per kilogram per day recovered from night blindness.

Experimental Procedure

This study, which was carried out with Fine-wool Texas feeder lambs, was divided into two parts. All lambs were drenched with phenothiazine. In addition to the usual factors considered in lotting experimental animals the initial plasma vitamin A values were also taken into account.

In the first experiment alfalfa meal and a carotene concentrate were compared at three levels of intake, 1940, 3880, and 5840 micrograms of carotene per lamb daily. Four of the six lots of lambs used in this experiment (lots 3, 4, 5 and 6) received a low-carotene basal ration for a period of 194 days prior to the feeding of the carotene supplements. Consequently, their initial plasma vitamin A values were low at the beginning of the experimental period. There were, however, no visible symptoms of a vitamin A deficiency. During the experimental period the lambs were given a constant amount of carotene with no adjustments being made for weight changes. All the lambs

were fed individually and received a "low-carotene" ration made up of 50 percent ground prairie hay, 35 percent rolled oats and 15 percent soybean oil meal. The hay used was several years old and so badly weathered that it contained no measurable amount of carotene. A mineral mixture of equal parts of dicalcium phosphate and salt was available to the lambs at all times.

The carotene concentrate used was Research Carrot Oil containing 14,920 micrograms of carotene per gram. This carrot oil was given to the lambs in gelatin capsules. The required amount of alfalfa meal was fed on top of the basal ration. The crude and "true" carotene contents of these supplements were determined at frequent intervals by a combination of the Peterson, Hughes, and Freeman (1937) procedure as modified by Peterson (1941), and the Wall and Kelley (1943) method. The latter method makes use of MgO to separate so-called "true" carotene from associated yellow pigments.

In the second experiment all the lambs were fed a low carotene basal ration composed of cottonseed hulls, oats, and cottonseed meal for a preliminary period of 90 days before initiating the experimental treatments. At this time four representative lambs were slaughtered and the vitamin A content of their livers determined in order to obtain some measure of the vitamin A storage of the lambs at the beginning of the experimental period.

Alfalfa meal and a fish liver oil were compared in the second experiment at two levels of intake. The lambs in two lots (lots 7 and 8) received 50 I.U.[4] of vitamin A per kilogram of body weight per day from alfalfa meal and a fish oil while two other lots (lots 9 and 10) were given ten times this amount, or 500 I.U. from the same two sources. These intakes represent approximately minimum and ten times minimum carotene requirements for the prevention of night blindness as established by Guilbert *et al.* (1937). Intakes were adjusted at frequent intervals to take care of weight changes and changes in carotene content of the alfalfa meal. Variations in the guaranteed potency of the fish liver oil as determined by colorimetric methods (Gallup and Hoefer, 1946) were negligible.

In both experiments blood samples were taken at frequent intervals and the citrated plasma analyzed for vitamin A by a modification of the Kimble (1939) procedure. At the conclusion of the experimental feeding periods representative lambs from each group were slaughtered and the storage of vitamin A in the liver determined. Early in the experiment the method of vitamin A analysis used for liver was that of Benham (1943). A procedure (Gallup and Hoefer, 1946) somewhat similar to that of Kaser and Stekol (1943) was adopted later. Both methods proved to be satisfactory when conditions were carefully controlled. Color intensities were measured with an Evelyn photoelectric colorimeter in the usual manner.

[4] International or U.S.P. units, assuming .6 microgram of beta carotene or .25 microgram of vitamin A equals one unit.

TABLE 1. THE VITAMIN A CONTENT OF THE BLOOD PLASMA AND LIVER OF LAMBS WHICH HAD RECEIVED CAROTENE OR VITAMIN A FROM DIFFERENT SOURCES AT VARYING LEVELS OF INTAKE

Lot No.	No. of lambs	Days	Source[2]	Average daily carotene or vitamin A intake		Average plasma vitamin A		Livers analyzed	Average liver vitamin A
				Per lamb	Per kg. wt.	Initial	Final		
				Micrograms	*Micrograms* (I.U.[1])	*Micrograms percent*	*Micrograms percent*	*Number*	*Micrograms per 100 gm.*
Experiment No. 1[3]									
1	9	55	Carotene conc.	5,820	155.2 (258.7)	25.6±1.44	24.9±1.78	2	1,294.4± 666.11
2	9	55	Alfalfa meal	5,820	157.3 (262.2)	25.8±1.34	30.5±1.48	2	4,340.0±2,443.97
3	3	92	Carotene conc.	3,880	100.5 (167.5)	12.9±2.62	21.3±1.27	2	308.8± 132.85
4	3	92	Alfalfa meal	3,880	99.2 (165.3)	13.4±3.03	27.1±1.23	2	690.1± 337.30
5	3	92	Carotene conc.	1,940	44.9 (74.8)	13.5±2.74	17.5±3.53	2	143.8± 40.75
6	3	92	Alfalfa meal	1,940	50.3 (83.8)	13.1±2.48	20.8±4.04	2	190.0± 34.32
Experiment No. 2[4]									
7	10	103	Alfalfa meal	1,164.0	30.0 (50)	26.5±3.12	21.0±1.79	4	209.1± 43.83
8	10	103	Fish liver oil	493.8	12.5 (50)	26.1±1.98	25.1±1.69	4	664.6± 235.82
9	10	103	Alfalfa meal	11,730.0	300.0 (500)	26.4±1.11	34.3±1.69	4	3,321.8± 136.32
10	9	103	Fish liver oil	4,775.0	125.0 (500)	26.4±2.26	33.8±2.08	4	19,742.5±1,686.40

[1] International or U.S.P. units, assuming .6 microgram of beta carotene or .25 microgram of vitamin A equals one unit.

[2] The carotene concentrate was Research Carrot Oil obtained from Nutritional Research Associates, Inc., South Whitley, Indiana.
The fish liver oil was a vitamin A concentrate produced by the Borden Vitamin Company, New York, N. Y.

[3] In Experiment No. 1 the lambs were given a contant amount of carotene throughout the experimental period. No adjustments were made for weight changes. The per kg. weight intake was calculated from the average weight of the lambs during the period.

[4] In Experiment No. 2 the supplements were given according to body weight.

Results and Discussion

The results obtained in this experiment are summarized in table 1.

It is evident from the data reported for experiment No. 1 that alfalfa meal consistently maintained a higher level of vitamin A in the blood than did the carotene concentrate, Research Carrot Oil. It is also apparent that more vitamin A was stored in the liver when alfalfa meal supplied the carotene than when the lambs were dependent on "Carrot Oil." The same relative differences were maintained regardless of the level of carotene intake or the state of vitamin A nutrition of the lambs. For example, lambs in lots 3, 4, 5, and 6 were practically depleted of their vitamin A reserves as shown by their very low initial plasma values, whereas, the lambs in lots 1 and 2 had plasma values within the normal range when the supplemental carotene feeding was started. Under both conditions the feeding of alfalfa meal resulted in an increased concentration of vitamin A in both the blood and liver.

Liver storage of vitamin A was quite variable as indicated by the standard errors. In general there was very little storage at the two lowest levels of intake, 1940 and 3880 micrograms of carotene per lamb daily. These results are in agreement with those of Peirce (1945) with sheep, Lewis and Wilson (1945) with calves, and Callison and Knowles (1945) with rats, with regard to the storage of vitamin A in the liver when the intake is limited.

Although it is recognized that the data are limited in number, it seems hardly likely that chance alone would account for the consistent differences obtained, and it must therefore be concluded that the carotene supplied as alfalfa had a higher biological value to the lambs than the carotene of Research Carrot Oil.

The lambs used in the second experiment had been placed on a low-carotene ration composed of cottonseed hulls, oats, cottonseed meal and a mineral mixture immediately after being received. After 90 days on this ration 4 representative lambs were slaughtered and their livers analyzed for vitamin A. The results of these determinations are shown in table 2. The remaining lambs were divided into four uniform lots and the alfalfa meal and fish liver oil given at two levels of intake, 50 units and 500 units per kilogram of body weight per day as described under "Procedure."

If it is assumed that the lambs which were retained for the experimental feeding period had approximately the same liver storage of vitamin A as the lambs slaughtered at the beginning of the trial, then it is evident that the feeding of either alfalfa meal or a fish liver oil in amounts sufficient to meet the minimum requirements for the prevention of night blindness (50 units per kilogram) did not maintain liver storage of vitamin A.

When the vitamin A or carotene intake was increased from 50 units to

500 units per kilogram of body weight there was a definite increase in the concentration of vitamin A in the blood. The blood levels of the lambs receiving alfalfa meal were practically the same as for the lambs receiving the fish liver oil. However, there was a marked difference between these two groups in liver storage. The four livers obtained from the lambs, which had received the oil, contained 19,742.5 ± 1,686.40 micrograms of vitamin A per 100 gm., whereas, the lambs on alfalfa meal had an average liver storage of vitamin A of only 3,321.8 ± 136.32 micrograms per 100 gm. This latter value is practically the same as for the lambs slaughtered at the beginning of the

TABLE 2. THE VITAMIN A CONTENT OF THE BLOOD AND LIVER OF LAMBS FED A LOW-CAROTENE RATION FOR A PERIOD OF 90 DAYS

Lamb No.	Vitamin A in blood plasma, micrograms per 100 ml.	Vitamin A in liver, micrograms per 100 gm.
230	44.3	3550.2
232	29.7	2693.1
235	35.8	3718.3
236	26.3	1421.8
Average	34.0	2845.9

experiment which would indicate that under the condition of this experiment it took approximately 10 times the minimum requirements for carotene in the form of alfalfa meal to maintain the initial liver storage of vitamin A.

It is interesting to note that at the lower level of vitamin A intake, 50 units per kilogram of body weight, the lambs receiving the fish liver oil maintained a liver storage of vitamin A approximately three times greater than that of the alfalfa meal lambs. However, when intake was increased ten times, or to 500 units per kilogram of body weight, the difference in liver storage of vitamin A was approximately six times in favor of the lambs receiving the fish liver oil. This result substantiates the earlier statement of Guilbert and associates (1937) that at low levels of intake carotene and vitamin A approach biological equivalence, but as the dosage is increased the comparative value of the vitamin A *per se* is increased.

It should also be pointed out that in spite of the great difference in liver storage of vitamin A between these two groups there was practically no difference in the vitamin A level in the blood. When blood values are normal there seems to be little relationship between the concentration of vitamin A in the liver and in the blood. Braun (1945) has found in cattle that a tendency toward a direct relationship between these two variables exists only when the values fall below normal.

The results obtained in this experiment and in others (Davies and Moore 1934; Gray *et al.* 1940; Wise *et al.* 1946) suggest that there is a limit to the ability of certain species to convert carotene to vitamin A. There is evidence indicating that even when animals are on green pasture and receiving an unlimited supply of carotene, they will not store as much vitamin A in the liver as animals which are given a relatively large amount of vitamin *per se* in the form of fish liver oil. During the period this second experiment was in progress an extra lamb was allowed to run on green pasture. He was killed along with the rest of the experimental lambs and a liver and blood sample taken for analysis. This lamb had 47.9 micrograms of vitamin A per 100 ml. of plasma and 7460 micrograms of vitamin A per 100 gm. of liver. The carotene intake of this lamb was very high and his plasma vitamin A was the highest of any of the lambs killed. However, liver storage of vitamin A was only moderately high and failed to approach that of the lambs receiving 500 units of vitamin A *per se* per kilogram of body weight. This inability to utilize large amounts of carotene efficiently also seems to hold true for rats. Davies and Moore (1934) failed in attempts to induce hypervitaminosis A in rats by feeding excessive amounts of carotene. Liver storage of vitamin A was only moderate. Wise and associates (1946) made observations with cattle which may be related to this problem. They found that the feeding of large quantities of vitamin A to dairy cows in the latter stages of gestation augmented significantly the vitamin A concentration in the blood and livers of their newborn calves, but pasture grazing, providing an abundance of carotene in the prepartum diet of the dams, failed to effect an increase over that observed in calves from dams restricted to a standard winter ration.

There was little variation in the average feed consumption and rate of gain between the lots of lambs receiving the various carotene and vitamin A supplements. Neither the kind of supplement or the level of feeding had a significant influence on the rate and economy of gain. This is in keeping with the report of Jones *et al.* (1943) that carotene in the ration of cattle has no effect upon gain or fattening so long as there are body reserves of vitamin A.

Summary and Conclusions

Fine wool feeder lambs, uniformly distributed with respect to vitamin A nutrition between comparable groups, were individually fed a low carotene ration with supplements of alfalfa meal, a carotene concentrate (Research Carrot Oil) and a fish liver oil. Alfalfa meal and the carotene concentrate were compared at levels of intake equivalent to approximately 79, 166 and 260 international units of vitamin A per kg. body weight, daily. The meal and fish liver oil were compared at accepted biological equivalent levels of 50 and 500 international units of vitamin A per kg. body weight, daily.

Values for the vitamin A content of the blood plasma, and liver storage of vitamin A at time of slaughter, were used as measures of the relative value of these supplements as sources of vitamin A for lambs.

The data collected in these experiments support the following conclusions:

1. Alfalfa meal is superior to a carotene concentrate from carrots as a source of vitamin A for lambs.
2. Fish liver oil is superior to alfalfa meal when fed on an equivalent unit basis, especially in the promotion of liver storage of vitamin A.
3. There is little direct relationship between values for blood plasma vitamin A and liver vitamin A when the blood plasma values are above 20 micrograms percent.
4. Values for the vitamin A content of the plasma of sheep between 20 and 45 micrograms percent may be considered within the normal range.
5. Additional vitamin A is without effect on the gaining ability of sheep that have appreciable body reserves of this vitamin.

Literature Cited

Benham G. H. 1943. Vitamin A and New-born Pigs. Can. Jour. Comp. Med., 7: 291.

Boyer, P. D., P. H. Phillips, N. S. Lundquist, C. W. Jensen and I. W. Rupel. 1942. Vitamin A and Carotene Requirements for the Maintenance of Adequate Blood Plasma Vitamin A in the Dairy Calf. Jour. Dairy Sci. 25: 433.

Braun, Werner. 1945. Studies of the Carotenoid and Vitamin A Levels in Cattle. Part II. Carotenoids and Vitamin A in the Liver, Their Ratio and Their Relationship to Blood Levels. Jour. Nutr., 29: 73.

Callison, E. C. and V. H. Knowles. 1945. Liver Reserves of Vitamin A and Their Relation to the Signs of Vitamin A Deficiency in the Albino Rat. Am. Jour. Physiol. 143: 444.

Davies, A. W. and T. Moore. 1934. Vitamin A and Carotene. Part XI. The Distribution of Vitamin A in the Organs of the Normal and Hypervitaminotic Rat. Biochem. Jour. 28: 288.

Fraps, G. S. and W. W Meinke. 1945. Relative Values of Carotene in Foods as Measured by Storage of Vitamin A in Livers of Rats. Food Res. 10: 187.

Gallup, W. D. and J. A. Hoefer. 1946. Determination of Vitamin A in Liver. Indus. & Eng. Chem., Anal. Ed., 18: 288.

Gray, E. L., K. C. D. Hickman and E. F. Brown. 1940. The State of Vitamin A in the Liver of the Rat After Feeding Various Forms of the Vitamin. Jour. Nutr. 19: 39.

Guggenheim, K. 1944. The Biological Value of Carotene from Various Sources and the Effect of Vitamin E on the Utilization of Carotene and of Vitamin A. Biochem. Jour. 38: 260.

Guilbert, H. R., R. F. Miller and E. H. Hughes. 1937. The Minimum Vitamin A and Carotene Requirements of Cattle, Sheep and Swine. Jour. Nutr. 13: 543.

Hauge, S. M., R. J. Westfall, J. W. Wilbur and J. H. Hilton. 1944. The Vitamin A Requirements of Dairy Cows for the Production of Butterfat of High Vitamin A Value. Part III. Availability of Carotene in Dehydrated Alfalfa Hay as Compared with Carotene in Oil. Jour. Dairy Sci. 27: 63.

Hilton, J. H., J. W. Wilbur and S. M. Hauge. 1944. The Vitamin A Requirements of Dairy Cows for the Production of Butterfat of High Vitamin A Value. Part II. Vitamin A *per se*. Jour. Dairy Sci. 27: 57.

Jones, J. H., H. Schmidt, R. E. Dickson, G. S. Fraps, J. M. Jones, J. K. Riggs, A. R. Kemmerer, P. E. Howe, W. H. Black, N. R. Ellis and Paul T. Marion. 1943. Vitamin A Studies in Fattening Feeder Calves and Yearlings. Texas Agric. Expt. Sta. Bul. 630.

Kaser, M. and J. A. Stekol. 1943. A Critical Study of the Carr-Price Reaction for the Determination of B-Carotene and Vitamin A in Biological Materials. Jour. Lab. and Clin. Med., 28: 904.

Keener, H. A., S. I. Bechdel, N. B. Guerrant and W. T. S. Thorp. 1942. Carotene in Calf Nutrition. Jour. Dairy Sci., 25: 571.

Kimble, M. S. 1939. The Photo-colorimetric Determination of Vitamin A and Carotene in Human Plasma. Jour. Lab. and Clin. Med., 24: 1055.

King, W. A., P. H. Phillips, M. E. Nesbitt, I. W. Rupel and G. Bohstedt. 1940. The Effect of Avitaminosis A Upon Vitamin C in the Bovine. Jour. Dairy Sci., 23: 568.

Lewis, J. M. and L. T. Wilson. 1945. Vitamin A Requirements in Calves. Jour. Nutr., 30: 467.

Moore, L. A. 1939. Carotene Intake, Level of Blood Plasma Carotene and the Development of Papillary Edema and Nyctalopia in Calves. Jour. Dairy Sci., 22: 803.

Moore, L. A., M. H. Berry and J. F. Sykes. 1943. Carotene Requirements for the Maintenance of a Normal Spinal Fluid Pressure in Dairy Calves. Jour. Nutr. 26: 649.

Peirce, A. W. 1945. The Effect of Intake of Carotene on the General Health and on the Concentration of Carotene and of Vitamin A in the Blood and Liver of Sheep. Aust. Jour. Exp'l. Biol. and Med. Sci., 23: 295.

Peterson, W. J., J. S. Hughes and H. F. Freeman. 1937. Determination of Carotene in Forage. Indus. & Eng. Chem., Anal. Ed., 9: 71.

Peterson, W. J. 1941. Recent Developments in Methods for Determining Carotene. Indus. & Eng. Chem., Anal. Ed., 13: 212.

Record, P. R., R. M. Bethke and O. H. M. Wilder. 1937. The Vitamin A Requirements of Chicks with Observations on the Comparative Efficiency of Carotene and Vitamin A. Poul. Sci., 16: 25.

Rubin, M., and H. R. Bird. 1941. Some Experiments on the Physiology of Vitamin A Storage in the Chick. Poul. Sci., 20: 291.

Smith, M. C. and L. Otis. 1941. Carotene Analysis of Vegetables and Fruits as a Basis for Prediction of Their Vitamin A Value. Food Res., 6: 143.

Wall, M. E. and E. J. Kelley. 1943. Determination of Pure Carotene in Plant Tissue. Indus. & Eng. Chem., Anal. Ed., 15: 18.

Ward, R. E., S. I. Bechdel and N. B. Guerrant. 1940. Carotene and Vitamin A in the Nutrition of Growing Dairy Cattle. Jour. Dairy Sci., 23: 115.

Wise, G. H., M. J. Caldwell and J. S. Hughes. 1946. The Effect of the Prepartum Diet of the Cow on the Vitamin A Reserves of Her Newborn Offspring. Science, 103: 616.

THE EFFECT OF COBALT ON GROWTH AND CERTAIN BLOOD CONSTITUENTS OF SHEEP

A. L. Pope, P. H. Phillips, and G. Bohstedt[1]
University of Wisconsin[2]

A SHEEP problem that had become increasingly serious in northern Wisconsin was called to the attention of the Experiment Station in 1944. This problem had manifested itself by greatly reduced lamb and wool crops throughout the area. It was thought to be largely a parasite problem but complicated by other known factors. Blood analyses of affected flocks indicated a profound anemia and a decrease in blood plasma vitamins A and C. Postmortem examinations revealed a heavy internal parasite infection.

Due to the relationship of certain minerals to anemia in general and because of the effect of parasites on hemoglobin, an experimental approach was made to this problem by nutritional means. The first attempt was concerned with the problem as it occurred in the field.

Field Experiment

The worst afflicted flock brought to the attention of the Experiment Station was a Shawano County flock. After the lambing season of 1944, this flock totaled approximately 1300 ewes and lambs. By fall of that year, 200 head were left, and although a few had been marketed, the majority had died of unknown cause. A general observation of the flock showed them to be unthrifty, weak, and emaciated. Blood analyses revealed the unthrifty sheep to be uniformly low in hemoglobin. There was a reduction of 10 percent in the ewes, 31 percent in the rams, and 53 percent in the lambs when compared with the few apparently normal sheep in the flock. The unthrifty sheep in this flock also had a lower vitamin A and ascorbic acid blood plasma concentration. On the basis of these data it was concluded that therapeutic measures were necessary to improve the hemoglobin formation and thereby bolster the vitamin A and ascorbic acid relationship since the low vitamin levels were undoubtedly a secondary complication.

Even though these sheep were heavily parasitized, the work of Winchester and Herrick (1946) during the previous summer with these same sheep showed no benefit from medication with three well-known anthelmintics. This failure of medication pointed to a nutritional deficiency as causing the syndrome.

[1] The authors wish to thank Mr. Harold Volland, Gresham, Wisconsin, for making certain phases of this work possible.

[2] Departments of Animal Husbandry and Biochemistry.

The character of the soil in this area is of sandy nature. Since this type of soil has been associated with mineral deficiencies, it was decided to test trace mineral elements mixed with salt. For this purpose the chief minerals known to have a stimulatory effect on the hemopoietic system and which might have been deficient in this area were administered.

To each 100 pounds of granular salt they were added in the following proportions:

10 gm. potassium iodide plus stabilizer
10 gm. cobalt sulphate ($CoSO_4 \cdot 7H_2O$)
100-gm. manganese sulphate (monohydrate)
100 gm. copper sulphate
200 gm. ferric oxide

The ferric oxide with its characteristic reddish color served mainly as a "tracer" for the mineral mixture. This mixture was very similar to the one used successfully by Wright (1941) where he fed iron, copper, magnesium, manganese, and cobalt to sheep that were emaciated and anemic.

These minerals were fed to the Shawano County flock during 1945, the year following the large loss. The results were remarkable. During the 1945 pasture season there were no death losses in the flock. The lambs were marketed off pasture in September and only three failed to bring top market price. These sheep were checked periodically by blood analyses following the mineral feeding, and have remained in a healthy, thrifty condition.

As mentioned previously, many other sheepmen throughout Northern Wisconsin were suffering death losses from unknown causes among their flocks, although not as severely as in the Shawano area. Therefore these same minerals were packaged in sufficient quantities to mix with 100 pounds of salt and sent to 105 flock owners in Douglas, Bayfield, Washburn, Sawyer, Barron, Rush, Price, St. Croix, Chippewa, Pepin, Taylor, Clark, Wood, Waupaca, and Oconto counties. These men were asked to report on the results of this mineral feeding after one year. Their combined data show a lambing percentage of 112 for all ewes fed the mineral mixture. The average age for all lambs when sold was between 6 and 7 months, and their average weight was 86 pounds. These results appear exceedingly favorable in light of their previous history. The mineral mixture was also fed in 1946 with excellent results.

While the mineral mixture seemed to relieve these sheepmen of immediate trouble it did not reveal which one of the minerals was of most value. To determine this a group of sheep from the afflicted area was brought to the Experiment Station for a more carefully controlled experiment.

Station Experiment

Materials and Methods

The ewes and their lambs for this experiment were from a farm in Shawano County, Wisconsin. Hay was also imported to the Experiment Station from that area. The hay was chopped and of rather poor quality.

Two ewes and their two lambs were allotted to lot I and three ewes and their three lambs to lot II. Both lots were fed all the hay they would consume. Since corn and corn gluten meal are known to be relatively low in cobalt, a grain mixture consisting of these two feeds was fed to complete the ration. Lot I was given access to granular iodized salt, and lot II granular iodized salt plus 1 ounce cobalt sulphate ($CoSO_4 \cdot 7H_2O$) per 100 pounds of salt as recommended by the Michigan workers (Baltzer *et al.*, 1941). Therefore the only variation in the treatment of these two lots was the addition of cobalt to the salt of lot II.

It was decided to test the significance of cobalt with the Shawano County hay since the sheep there had shown symptoms very similar to a cobalt deficiency, namely, loss of appetite, anemia, and unthriftiness. Previous work (Geyer, Rupel, and Hart, 1945) with dairy cattle in Door County directly east of Shawano County had also shown beneficial results from cobalt administration.

Each ewe in lot II was fed 1⅓ pounds of grain per day throughout the experiment and consumed an average of 4 pounds of hay daily. Although the lambs of both lots had access to grain in a creep they were limited to 1½ pounds of grain per head daily. The lot I ewes were fed 1⅓ pounds of grain apiece daily (the same as lot II) until their appetite decreased, at which time they were fed the amount they would eat. After their appetite increased following cobalt feeding they were limited to 2 pounds of grain daily per head.

Weights were obtained periodically and because of the close relationship between cobalt and blood composition, blood analyses were made on the same day. The blood was analyzed for hemoglobin, vitamin A, and vitamin C.

Results

The experiment was started June 28, 1945, and at the end of two months on the experiment there was no significant difference between the two lots with respect to growth, hemoglobin, or blood plasma vitamins A and C. Both groups were thrifty, in good condition, and eating with avidity as the hay consumption of both lots was approximately the same. However, during the first week in September the sheep in lot I began refusing their feed. About this time the lambs in lot I stopped eating grain from their creep but

Figure 1 (top). Lot I ewes and lambs after 4½ months on the experimental ration plus only plain salt.

Figure 2 (bottom). Lot II ewes and lambs after 4½ months on the experimental ration plus cobaltized salt.

nibbled some grain in the ewe's rack and consequently began losing weight. This difference in feed consumption between the two groups continued to increase until by the first of November each sheep in lot I was consuming

less than ¼ pound of grain and about 1 pound of hay per day. A week later they were eating so little grain, it was hardly detectable by the daily weigh-back.

The lot I sheep at this time were typical of the sheep observed dying in the field the previous year.

On November 12 the lot I lambs weighed only 65 pounds apiece as compared to the cobalt-fed lambs' average of 115 pounds. The blood hemoglobin values of the lambs receiving cobalt were 23 percent higher than the non-

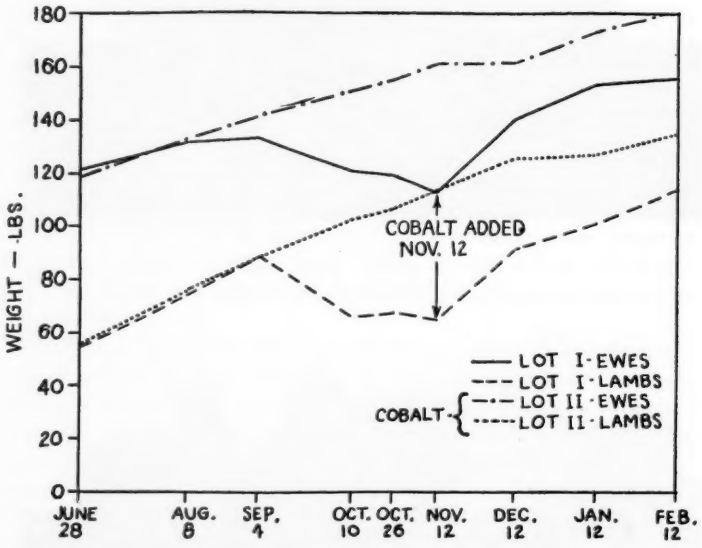

Figure 3. The effect of cobalt on the growth of sheep fed Shawano County hay plus corn and corn gluten meal.

cobalt fed lambs. A fecal worm egg count showed no significant difference between the two groups, and in both cases the parasite infection was slight. Figures 1 and 2 illustrate the difference in condition between the two lots at this stage of the experiment. On this date it was apparent that the Lot I sheep would actually starve to death unless their ration was altered in some respect. Therefore cobalt sulfate was added to their salt at the same rate it had been fed to the sheep in lot II, or 1 ounce per 100 pounds. No attempt was made to force the lot I sheep to eat the cobaltized salt since it was simply placed in their salt box. These sheep were not deprived of salt prior to offering them access to the salt containing cobalt.

The effect of feeding cobalt to lot I was almost instantaneous. Within three days their appetite was markedly improved, and after one week they were consuming the same amount of feed they were at the start of the experiment. Their good appetite continued and at the end of one month the lambs had an average gain of 26 pounds or 0.87 pound per day. While the

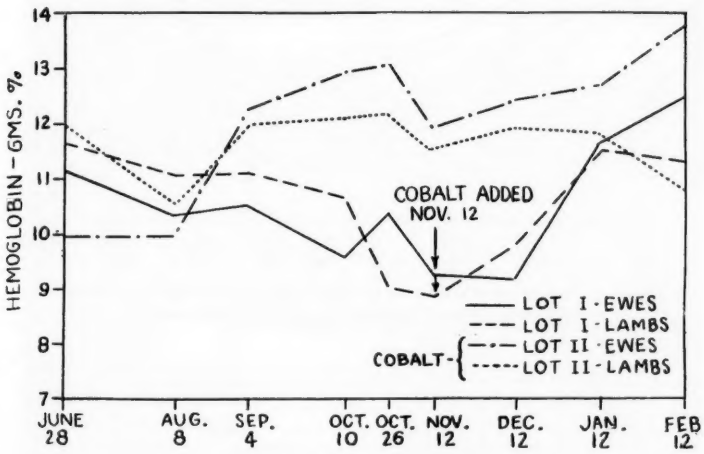

Figure 4. The effect of cobalt on the hemoglobin of sheep fed Shawano County hay plus corn and corn gluten meal.

lambs' hemoglobin also increased soon after the cobalt administration, the ewes' hemoglobin did not rise until the second month as shown in figure 4. Vitamins A and C blood plasma of both the ewes and lambs showed higher values after the first month.

Discussion

Where a cobalt deficiency in Northeastern Wisconsin has been proved to affect cattle, resulting in unthriftiness and anemia, the effects of such a deficiency were not as disastrous as in the case of sheep. The latter are subject to more severe internal parasite infection, therefore are apt to have one anemia producing factor superimposed on the other, as was the case in the large flock referred to. Without first correcting the cobalt deficiency, this flock did not respond to treatment with vermifuges.

Cobalt alone was effective in improving the experimental sheep showing identical symptoms with those dying in the field. Thus it may be safe to conclude that it was the element chiefly responsible for the beneficial results

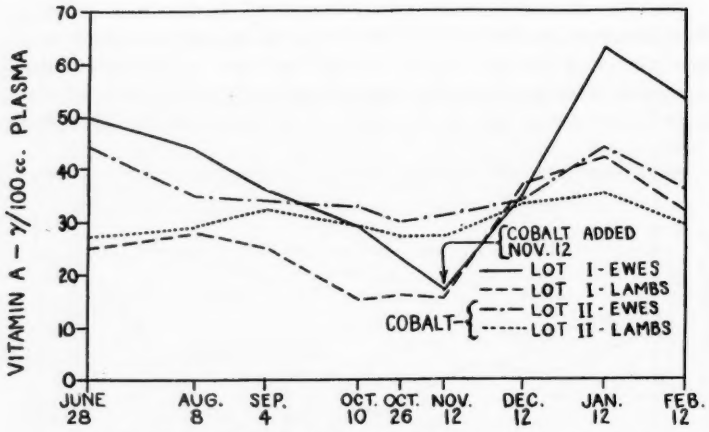

Figure 5. The effect of cobalt on the blood plasma vitamin A of sheep fed Shawano County hay plus corn and corn gluten meal.

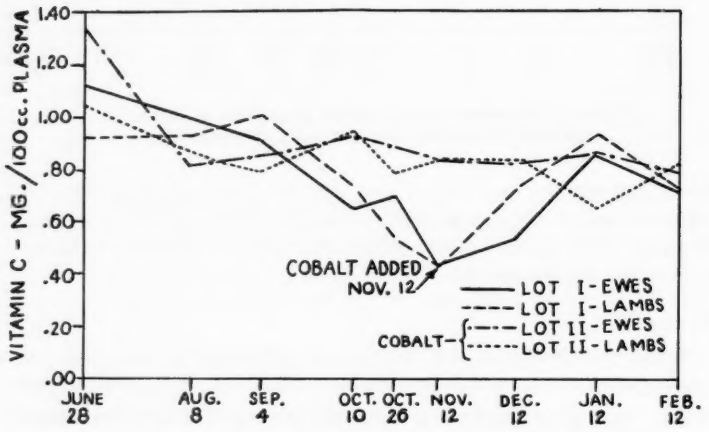

Figure 6. The effect of cobalt on the blood plasma vitamin C of sheep fed Shawano County hay plus corn and corn gluten meal.

experienced by Northern Wisconsin sheepmen after feeding a mineral mixture containing iodine, copper, manganese, iron, and cobalt. However this cannot be definitely ascertained without further experimentation.

It may be observed from figures 3, 4, 5, and 6 that hemoglobin improve-

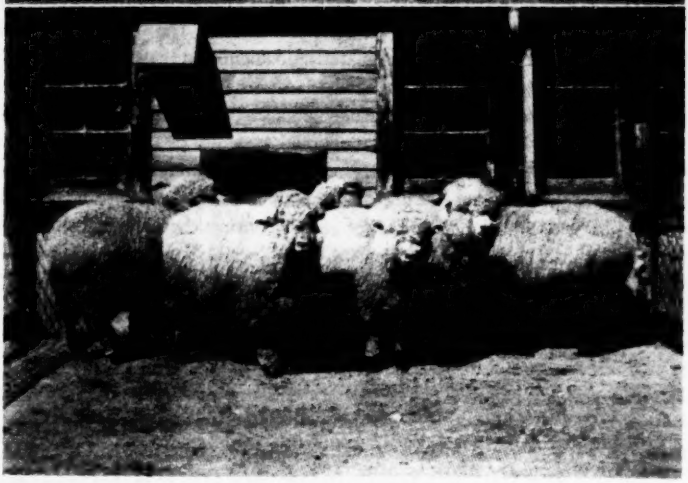

Figure 7 (top). Lot I ewes and lambs at the close of the experiment and after receiving cobalt for 3 months following a deficiency.

Figure 8 (bottom). Lot II ewes and lambs at the close of the experiment and having received cobaltized salt throughout.

ment was slow when cobalt was given, especially in the case of the ewes, while growth and the blood plasma concentration of vitamins A and C rapidly increased.

Since the most important effect of supplementing cobalt in the salt of lot I was the rapid improvement in appetite of the sheep, the increase in body weight was undoubtedly due to the increased feed consumption of these animals. Likewise, the increase in the blood plasma vitamins was probably a reflection of the rapid increase in appetite. The apparent lag with respect to hemoglobin improvement following cobalt feeding is difficult to explain especially since the specific function of cobalt in the body is not thoroughly understood. A possibility might be that the flora and fauna of the rumen are altered during a cobalt deficiency. Since these microorganisms may have a hemopoietic effect, they perhaps require a period of time after cobalt administration before reaching full function, and hence the time lapse before a noticeable improvement in the hemoglobin concentration. Another assumption might be that if iron and copper had been fed with the cobalt, a more rapid rise in hemoglobin would have occurred.

Summary

When iodine, cobalt, manganese, copper, and iron were supplied to many Northern Wisconsin sheep, death losses were reduced, the lamb crop greatly increased, and sheep that were emaciated and anemic were greatly improved.

Symptoms very similar to those of sheep dying in the field were produced experimentally with sheep from the affected area by feeding a ration of corn, corn gluten meal, and hay from the afflicted area.

Symptoms of appetite loss, emaciation, and anemia were quickly alleviated by the addition of 1 ounce of cobalt sulphate to 100 pounds of salt, fed free choice. The most noticeable effect of supplementing the ration with cobalt was the rapid resumption of appetite. This increased feed intake was reflected by a sharp increase in growth and in blood plasma vitamins A and C.

Hemoglobin formation following cobalt therapy returned to normal slowly and was not as rapid as the appetite and growth responses.

Literature Cited

Baltzer, A. C., B. J. Killham, C. W. Duncan and C. F. Huffman. 1941. A Cobalt Deficiency Disease Observed in Some Michigan Dairy Cattle. Mich. Agric. Expt. Sta. Quart. Bul. No. 1, 24: 68–70.

Geyer, R. P., J. W. Rupel and E. B. Hart. 1945. Cobalt Deficiency in Cattle in Northern Wisconsin. Jour. Dairy Sci., 28: 291–296.

Winchester, B. and C. A. Herrick. 1946. Some Effects of Administering Copper Sulphate, Copper-Nicotine, and Phenothiazine with and without Cobalt Supplement. Journal of Animal Science, 5: 417.

Wright, W. L. 1941. Suggestive Evidence of Trace Mineral Deficiency in Illinois Sheep. Veter. Med., 36: 572–573.

THE INFLUENCE OF PROTEIN SOURCE UPON NITROGEN RETENTION BY SHEEP

G. P. Lofgreen, J. K. Loosli and L. A. Maynard[1]
Cornell University

VARIOUS studies have clearly shown that ruminants can make use of non-protein-nitrogen compounds in lieu of a part of the protein intake required for growth and maintenance. The explanation seems to be that microorganisms in the rumen can use non-protein-nitrogen to build their body protein which is in turn digested in the true stomach and intestines. Johnson and associates (1942, 1944) found that a considerable proportion of the protein ultimately utilized by the ruminant is bacterial protein regardless of the nature of the nitrogen contained in the ration. They have proposed the thesis that with sheep "the biological value of the nitrogen of rations containing 10 to 12 percent of crude protein (nitrogen × 6.25) generally varies only within a few percent of 60." While there are many data in the literature which lend support to this conclusion there are also several exceptions. Sotola (1930) reported biological values of 81 and 62 for alfalfa hay plus corn silage and alfalfa hay plus sunflower silage, respectively. Turk and associates (1934, 1935) have found values of 79, 77, 81, 80, 65.7, 67.7, and 72.8 for various feeds and feed combinations. Smuts and Marais (1939) reported a biological value of 74 for fishmeal. The mean of these values plus those tabulated by Johnson and associates is 65.8 ± 8.1, thus 32 percent of the values would fall outside the limits of 57.7 to 73.9. It has been found in this laboratory (Loosli and Harris, 1945) that when approximately 40 per cent of the total nitrogen of a ration was furnished in the form of urea the nitrogen retention was markedly improved by the addition of methionine.

In view of these data it seemed worthwhile to obtain further information as to whether the nature of the nitrogen fed is of importance in the case of sheep. The present paper, therefore, reports a nitrogen balance study in which the previous comparison with and without methionine was repeated, and in which a further comparison was made with linseed meal and with a protein source of known high biological value for rats, namely dried egg.

Experimental Procedures

Six grade western wethers of approximately uniform breeding, and weighing between 50 and 55 pounds were placed on a nitrogen balance experiment in which each lamb received in different periods each of the four experimental

[1] Laboratory of Animal Nutrition, Ithaca, N. Y.

rations shown in table 1. It is noted that the rations were approximately equal in total nitrogen content, the values corresponding to a calculated protein content (nitrogen × 6.25) of 10 percent. In each case timothy and corn furnished 60 percent of the total nitrogen of the ration, while the various nitrogen supplements furnished the remaining 40 percent. The methionine furnished 1.2 percent of the total nitrogen and sufficient sulfur to make the nitrogen to sulfur ratio in the supplements equal to 15:1. Thus a much smaller percentage of the amino acid was included than in the previously

TABLE 1. COMPOSITION OF RATIONS, IN PERCENT ON AN AIR DRY BASIS

Ingredients*	Basal ration plus:			
	Urea	Urea and methionine	Linseed meal	Dried egg
Timothy	40.00	40.00	40.00	40.00
Corn	20.90	20.90	20.90	20.90
Urea	1.38	1.34	—	—
Methionine[1]	—	0.20	—	—
Linseed meal	—	—	12.00	—
Egg	—	—	—	8.60
NaCl	0.60	0.60	0.60	0.60
Dicalcium phosphate	0.96	0.96	0.48	0.96
Limestone	0.43	0.43	0.61	0.43
Cerelose (Dextrose)	6.66	6.66	6.66	6.66
Starch	29.07	28.91	18.75	21.85
Total	100.00	100.00	100.00	100.00
Protein content, percent (N×6.25)	10.18	10.20	10.17	9.98

* A weekly supplement of vitamins A and D was fed in addition to the above ration.

[1] The methionine used in this study was kindly furnished by the E. I. du Pont de Nemours & Co., Wilmington, Del.

reported experiment and a more rigid test of its value was therefore accomplished.

For two weeks prior to being placed on the experimental rations the lambs were fed cracked corn and the timothy hay which was to be fed during the experiment. During this time the proportion of roughage to concentrate of 1:1.5 was adjusted as well as the total quantity of feed to be consumed. Feed intakes were adjusted to 150 percent of maintenance (Brody and associates, 1934). After they were eating the feed in the amounts desired the experimental concentrate mixture was substituted in place of the corn. Preliminary periods were of at least seven days duration and collections were

made for ten days. Weights were taken on three successive days at the beginning and end of the collection periods.

Results and Discussion

The nitrogen balance results are presented in table 2. These data reveal that the addition of methionine to a ration containing urea increased the proportion of the dietary nitrogen retained. This difference was statistically significant at the five percent level of significance. In the case of every lamb

TABLE 2. NITROGEN BALANCE DATA, ON A DAILY BASIS

	Basal ration plus:			
	Urea	Urea and methionine	Linseed meal	Dried egg
Average gain, lbs.	0.15	0.11	0.22	0.42
Nitrogen intake, gms.	12.80	12.90	12.67	14.69
Nitrogen intake, gms. per kilo.	0.48	0.48	0.47	0.42
Nitrogen absorbed, gms.	7.17	7.63	7.31	8.96
Urinary nitrogen, gms.	4.10	3.85	3.54	3.81
Nitrogen retained, gms.	3.07±0.25*	3.77±0.30	3.73±0.26	5.15±0.38
Nitrogen retained, as percent of dietary	23.9 ±1.5	29.0 ±1.5	29.5 ±1.5	35.4 ±2.5
Nitrogen retained, as percent of absorbed	42.5 ±2.1	49.1 ±2.6	51.0 ±2.6	57.9 ±3.5
Apparent digestibility of nitrogen, percent	56.0 ±1.1	59.1 ±1.0	57.7 ±0.7	60.8 ±2.0
True digestibility of nitrogen, percent**	86.3 ±1.1	89.3± 0.9	88.1 ±0.7	91.2 ±1.9
Calculated biological value of protein**	71 ±1.2	74 ±1.8	76 ±1.7	80 ±2.1

* Standard error of the mean.

** Endogenous nitrogen =0.033 gm. per kilogram body weight. Metabolic nitrogen =0.55 gm. per 100 gm. dry matter intake (Harris and Mitchell, 1941).

methionine improved the nitrogen retention up to the level of that for the linseed meal ration. These data confirm the results of Loosli and Harris (1945) in demonstrating the value of methionine in supplementing urea. One-sixth of the amount previously fed is sufficient to produce this effect. There were no significant differences in digestibility of either protein or dry matter nor in gains in weight over the 10-day collection periods.

The amount of nitrogen retained and the high biological value of 80 obtained for the protein of the egg ration are striking. It appears that the quality of this protein has had an effect upon the nitrogen metabolism of the lambs. The endogenous and metabolic nitrogen excretion values used in the

calculations are average values except in the case of two lambs whose endogenous and metabolic nitrogen excretion was determined during a period on a low-nitrogen ration. Whether the average values or the determined values were used in the calculations made little difference in the results. The difference between the egg protein and linseed meal protein was significant at the five percent level of significance and for egg over urea at the one percent level. The biological value for urea reported here is considerably higher than 60, and those for linseed meal and egg protein are definitely above. Additional weight is given these calculated biological values when one considers the high percentage of absorbed nitrogen retained compared to those obtained by Johnson and associates (1944) on rations in which urea furnished 83 percent of the nitrogen. Lambs on such a ration retained an average of 15.3 percent of the absorbed nitrogen while those reported in this experiment retained 42 percent on the urea ration, 49 percent on the urea plus methionine, 51 percent on the linseed meal, and 58 percent on the dried egg ration. Thus, these data indicate that there are differences in the biological value of various proteins when fed to lambs at a level of 10 percent crude protein and that they may vary widely.

The theory that in ruminants, maintained on the usual feeding stuffs, dietary nitrogen is largely converted to bacterial protein before it is digested and absorbed may generally be true. In lambs, however, the facts that urea is of lower value than true protein, that methionine increases the retention of nitrogen from rations containing urea, and that egg protein is markedly superior to other proteins tested in promoting nitrogen retention places emphasis on the concept that the quality of a protein may be of importance for this species. The question as to the adequacy of bacterial protein needs study as does the specific nutritive needs of the rumen bacteria. In this connection it has been shown that yeast protein is deficient in methionine (Klose and Fevold, 1944), and that certain bacteria require methionine for growth (Niven, 1944). It is not known, however, whether these same relationships are true for the microflora of the rumen.

It is entirely logical to assume that the physiological needs of ruminants for amino acids are probably similar to those of non-ruminants. Whether bacterial protein from the rumen will fully satisfy these needs has not been demonstrated. Since glucose is readily absorbed from the rumen (Rankin, 1942), it appears likely that amino acids may also be so absorbed. Thus, it may be possible that varying amounts of amino acids may be absorbed before they can be used by rumen microorganisms, depending upon the nature of the protein being ingested. Clearly, therefore, the nitrogen actually available for the physiological needs of ruminants may fluctuate considerably in the proportion of dietary and bacterial protein, thus partially explaining the

comparatively high biological value of egg protein and variations reported for other feed combinations.

Conclusions

The addition of 0.2 percent methionine to a ration containing 10 percent protein (nitrogen × 6.25) with urea furnishing 40 percent of the total nitrogen significantly increased the nitrogen retained by the lambs used in this experiment.

These same lambs utilized egg protein significantly better than linseed meal protein or that synthesized from urea.

These results suggest that the quality of protein as fed in the rations of lambs may be of importance under certain conditions. It seems logical to assume that if protein quality has an effect upon the nitrogen retention of lambs that it may have some similar effect upon gains in weight in feed lot operations.

Literature Cited

Brody, S., R. C. Procter and U. S. Ashworth. 1934. Growth and Development. XXXIV. Basal Metabolism, Endogenous Nitrogen, Creatinine and Neutral Sulfur Excretions as Functions of Body Weight. Mo. Agric. Exp. Sta. Res. Bul. 220, 40 pp.

Harris, L. E. and H. H. Mitchell. 1941. The Value of Urea in the Synthesis of Protein in the Paunch of the Ruminant. I. In Maintenance. Jour. Nutr. 22: 167–182; II. In Growth, *ibid.*, 22: 183–196.

Johnson, B. C., T. S. Hamilton, H. H. Mitchell and W. B. Robinson. 1942. The Relative Efficiency of Urea as a Protein Substitute in the Ration of Ruminants. JOURNAL OF ANIMAL SCIENCE, 1: 236–245.

Johnson, B. C., T. S. Hamilton, W. B. Robinson and J. C. Garey. 1944. On the Mechanism of Non-Protein-Nitrogen Utilization by Ruminants. JOURNAL OF ANIMAL SCIENCE, 3: 287–298.

Klose, A. A. and H. L. Fevold. 1944. Methionine Deficiency in Yeast Protein. Proc. Soc. Exptl. Biol. and Med., 56: 98–101.

Loosli, J. K. and L. E. Harris. 1945. Methionine Increases the Value of Urea for Lambs. JOURNAL OF ANIMAL SCIENCE, 4: 435–437.

Niven, C. F., Jr. 1944. Nutrition of Streptococcus Lactis. Jour. Bact., 47: 343–350.

Rankin, A. D. 1942. Studies on Absorption from the Rumen. Fed. Proc., 1: 70.

Smuts, D. B. and J. S. C. Marais. 1939. The Biological Value of White Fishmeal as Determined on Growing Sheep and Rats. Onder. Jour. Vet. Sci. and An. Ind. 13: 361–366.

Sotola, J. 1930. Biological Values and Supplementary Relations of the Proteins in Alfalfa Hay and Corn and Sunflower Silage. Jour. Agr. Res. 40: 79–96.

Turk, K. L., F. B. Morrison and L. A. Maynard. 1934. The Nutritive Value of the Proteins of Alfalfa Hay and Clover Hay when Fed Alone and in Combination with the Proteins of Corn. Jour. Agr. Res., 48: 555–570.

Turk, K. L., F. B. Morrison and L. A. Maynard. 1935. The Nutritive Value of the Proteins of Corn-Gluten Meal, Linseed Meal, and Soybean Oil Meal. Jour. Agr. Res., 51: 401–412.

CONTENT AND DIGESTIBILITY OF MORNING AND EVENING CUTTINGS OF ALFALFA

WILLIAM H. ADOLPH,[1] H. A. MACDONALD, HUI-LAN YEH AND G. P. LOFGREEN[2]

Cornell University[3]

CURTIS (1944) has reported that alfalfa plots cut in the evening yielded an average of 19 percent more total dry matter than similar plots cut in the morning. He suggests that, where other considerations do not interfere, there would be a distinct advantage in cutting alfalfa and other forage crops in the afternoon rather than in the morning. Furthermore, Curtis feels that the greater part of the gain in total dry matter during the daytime exposure to sunshine is a gain in easily digestible materials and that there should actually result a gain in feeding value much greater than that represented by the increase in dry matter. It is desirable to know if feeding tests with animals show an increase in nutritive value. The present report records an experiment to compare the digestibility of morning and evening cuttings of alfalfa hay.

Experimental

A field of second cutting alfalfa in the early bloomstage was selected for use in this study. Thirty-six field plots, twelve replicates each of three times of cutting, were used. Morning harvest was made at 8:00 A.M. and the evening harvests at 5:30 P.M. on September 16 and 17, 1945. The material from six plots of each treatment was taken immediately to the oven for rapid drying. The remaining six replicates of each time of cutting remained in the field, in the swath condition, for curing. Curing to 18 to 24 percent moisture content required 34 hours in the case of the morning cut alfalfa and about 48 hours for that cut in the evening. By careful handling leaf loss was avoided during curing. The weather was fine and clear throughout the period of the field investigations. After field-curing these samples were also oven-dried for uniform moisture content.

A summary of the alfalfa yield data is presented in table 1.

An analysis of the data in table 1 shows no significant change in the yield of alfalfa. Although the mean yield of dry matter shows a slight gain during the period of the study, no significant gain or loss was found between that cut in the evening and that cut the next morning or the following evening. This was true for the crop as cut and also following field curing.

[1] Present address, Yenching University, Peiping, China.

[2] The authors acknowledge the assistance of R. F. Elliott in making the chemical analyses.

[3] Departments of Animal Husbandry and Agronomy, Ithaca, New York.

A significant curing loss was found in all cases where the alfalfa was harvested in the evening. The loss in curing did not quite reach significance in the case of the morning-cut crop. This great loss associated with evening cutting was apparently due to the longer time required in field-curing which resulted in a greater respiration loss.

Both the rapid-dried and the field-cured alfalfa were used in feeding trials.

TABLE 1. SUMMARY OF ALFALFA YIELDS

Time of cutting	Dry matter yield	
	When cut	After field curing
	lbs./acre	*lbs./acre*
Evening	2884	2693*
Morning	2991	2728
Evening	3060	2821*

* Statistically significant curing losses.

TABLE 2. ANALYSIS OF ALFALFA FED (IN PERCENT)

Time of cutting	Dry matter	Nitrogen	Ash	Ether extract	Crude fiber	N-free extract	Lignin	Total sugar	Starch
Oven Dried									
Evening	91.9	2.70	6.49	1.84	25.4	41.3	8.69	4.23	2.89
Morning	92.2	2.74	6.75	1.84	28.1	38.4	9.52	3.64	2.48
Evening	91.6	2.68	6.35	1.80	25.3	41.4	8.60	4.03	3.43
Field Cured									
Evening	92.0	2.68	6.33	1.17	27.3	40.4	8.93	6.33	1.42
Morning	92.6	2.70	6.45	1.13	27.7	40.4	9.35	5.74	1.57
Evening	92.4	2.58	6.03	1.22	28.3	40.8	9.02	6.74	1.43

Each of the six treatments shown in table 2, involved material harvested from six plots which were then composited. The six composite lots constituted the sole diet of the rabbits in the digestion studies. Approximately 35 pounds of dry material from each of the six treatments were available for the feeding experiments. The material was ground in a hammer mill and stored in metal containers until used.

Six rabbits, each weighing 1.2–1.3 kilos, were used and carried through each of six feeding periods in the fall of 1945. For each period, each rabbit was fed one of the alfalfa hays and the diets then rotated in succeeding periods. A uniform regime of equalized intake for the six animals was fol-

lowed, the amount of alfalfa fed being limited in each period as far as possible to that of the animal consuming the least. The usual care was taken with feed spilled or left in the feed cups. These amounts were usually small and almost negligible.

Before the beginning of the experiment, the animals were fed for one month on alfalfa to accommodate them to this type of feed. The feeding periods were 13 days in length; collection of fecal material being limited to the last

TABLE 3. DIGESTIBILITY OF ALFALFA

Constituent	Time of cutting			Mean
	Evening	Morning	Evening	
Oven Dried				
Dry matter	55.7±1.5*	54.3±1.5	57.1±1.2	55.7
Protein (N×6.25)	70.1±1.8	70.7±1.5	71.3±2.3	70.7
N-free extract	72.1±2.0	69.9±2.5	72.8±2.5	71.6
Crude fiber	13.5±2.8	18.0±3.0	16.7±2.1	16.1
Lignin	3.0±2.6	8.2±3.6	6.2±3.3	5.8
Total digestible nutrients	46.9	45.9	48.1	47.0
Field Cured				
Dry matter	52.9±1.3	53.3±1.6	53.7±1.8	53.3
Protein (N×6.25)	71.3±2.0	73.3±1.3	72.8±1.9	72.5
N-free extract	69.7±1.2	72.0±2.8	70.4±1.9	70.7
Crude fiber	12.0±4.0	9.2±2.7	14.7±4.5	12.0
Lignin	2.1±3.4	5.4±5.1	2.7±4.3	3.4
Total digestible nutrients	44.6	45.2	45.8	45.2

* ± Figures represent the standard error of a single observation.

10 days. The rabbits maintained body weights constant within 0.2 kilo throughout the three months of the experiment.

The fecal material was collected daily and after slight crushing was dried in a current of air at room temperature. The total 10-day sample for each rabbit was then ground through a Wiley mill and mixed thoroughly. The fecal material was analyzed for dry matter, nitrogen, crude fiber and nitrogen-free extract, using the A.O.A.C. methods of analysis, and for lignin using the method developed by Ellis *et al.* (1946). These same determinations and in addition a determination of ether extract, total sugar and starch were also carried out on the material fed. Samples of the alfalfa fed were taken, one at the beginning and another at the close of the feeding experiment and the results averaged. These analyses are shown in table 2.

Calculation of digestibility was carried out for dry matter, nitrogen, crude fiber, nitrogen-free extract and lignin. The average figures for the digestion coefficients for the six rabbits are shown in table 3.

A statistical analysis of the data in table 3 reveals that in the case of every constituent except protein the digestion coefficients of the oven-dried samples were significantly higher than those of the field-cured samples. For protein the opposite was true.

In only one instance was there a significant difference in digestibility when morning and evening cuttings of alfalfa were compared. The digestibility of the dry matter of the hay cut on the evening of the 17th and subjected to oven-drying was significantly higher than that cut in the morning of the same day and oven-dried.

The high variability noted in the digestibility of the lignin in these hays is noteworthy since it has been suggested (Ellis *et al.*, 1946) that lignin might be used as a reference material in the calculation of digestibility. In the present study an average of approximately 95 percent of the lignin was recovered in the feces. This figure compares favorably with that reported by Ellis and associates for one group of rabbits fed Sudan grass but is lower than that for another group fed similar grass. The large variation in the degree to which different animals digest lignin and the fact that its digestibility may amount to 5 percent or more would introduce considerable error in digestion coefficients calculated by the use of lignin ratios.

Summary

In the experiment reported no significant difference in dry matter yield was found between alfalfa cut in the evening and that left for cutting the following morning. The evening-cut samples required an average of fourteen additional hours for field-curing. Significant curing losses occurred in the evening-cut alfalfa. The curing losses from morning-cut samples were less and did not reach significance in this investigation.

A digestibility experiment with rabbits shows no pronounced difference between the digestibility of morning and evening cuttings of alfalfa hay. Oven-dried samples of alfalfa showed higher digestibility of carbohydrates but lower digestibility of protein than similar field-cured hay.

Literature Cited

Association of Official Agricultural Chemists. Methods of Analysis, Washington, D. C., 1935.

Curtis, O. F. 1944. The Food Content of Forage Crops as Influenced by the Time of Day at Which They are Cut. Jour. Am. Soc. Agron., 36: 401–416.

Ellis, G. H., G. Matrone and L. A. Maynard. 1946. A 72 Percent H_2SO_4 Method for the Determination of Lignin and its Use in Animal Nutrition Studies. JOURNAL OF ANIMAL SCIENCE, 5: 285–296.

IMPAIRMENT IN NUTRITIVE VALUE OF CORN GRAIN DAMAGED BY *NIGROSPORA ORYZAE*

H. H. Mitchell, Jessie R. Beadles, Benjamin Koehler and George H. Dungan

University of Illinois[1]

THE extent of infection of the corn grain by fungi of various kinds is an important item in the grading of corn by physical or chemical means or by performance tests. It may also be an important item in the feeding value of the grain for livestock.

Mitchell and Beadles (1940) have studied the impairment in the nutritive value of corn by various types of ear rot, using growing albino rats as test animals. They reported that infection with diplodia or fusarium ear rot definitely lowered the digestibility of both protein and energy in corn, as well as the growth promoting value. A sample of corn containing 53 percent of kernels damaged by the gibberella organism was extremely toxic for the young albino rat.

Many references in the literature reporting observations on the feeding value, or the toxicity, of "moldy" corn are difficult to evaluate because the type of the infective organisms was not identified.

Usually the *Nigrospora oryzae* organism is of small importance in the state of Illinois as a corn-damaging agent, but in 1945 it occasioned the most prevalent type of ear rot. Quoting Dungan and associates (1946): "In some parts of the state it was most damaging to the late-planted corn that was caught by frost. It also occurred more than usual in many early fields. Nigrospora makes the cobs fragile. Part of the loss from it comes during husking, when the cobs are apt to break. Broken cobs mean corn wasted on the ground."

Since many inquiries have been received from livestock feeders concerning the feeding value of corn infected with this fungus, tests were made with such damaged corn using young albino rats as subjects. Essentially the same technic was used as that employed previously by Mitchell and Beadles (1940).

Experimental Procedure

Two lots of corn were selected from Pfister hybrid 360 grown in 1945 in the same field in north central Illinois. One lot contained ears severely infected with *Nigrospora oryzae*, while the other lot contained ears as nearly sound as could be determined by general inspection.

After shelling the two lots of corn, naked eye inspection of 300 kernels

[1] Division of Animal Nutrition and Department of Agronomy, Urbana, Illinois.

taken with a Boerner sampler from each lot for the presence of clusters of black spores of *Nigrospora oryzae* indicated a 53.3 percent incidence in the one lot and an incidence of only 1.7 percent in the other. Hereafter, these lots will be referred to as "unsound" and "sound" corn, respectively.

Fungus identification on 100 kernels selected with the same sampling device from each lot was made with the microscope, all kernels being surface

TABLE 1. FUNGUS IDENTIFICATION ON SOUND AND UNSOUND SAMPLES OF CORN, EXPRESSED AS PERCENTAGES OF INFECTED KERNELS

Fungi	Unsound corn, percent	Sound corn, percent
Nigrospora oryzae	89	14
Diplodia zeae	1	1
Gibberella zeae	3	2
Fusarium moniliforme	2	2
Hormodendrum sp.	2	5
Unidentified	1	2

TABLE 2. CHEMICAL COMPOSITION OF THE CORN SAMPLES AND WEIGHT PER 100 KERNELS

Sample	Weight of 100 kernels	Moisture	Protein, (N×6.25)	Ether extract	Crude fiber	Ash	Gross energy
	gms.	*percent*	*percent*	*percent*	*percent*	*percent*	*Cals./gm.*
Sound corn	21.13	10.01	8.75	3.83	2.48	1.20	4.064
Unsound corn	17.84	11.18	8.12	3.24	2.60	1.26	3.976

sterilized and plated on potato dextrose agar in petri dishes. The results of this test are assembled in table 1.

Representative samples of the sound and unsound corn were submitted to chemical analysis and weights were taken of 100 kernels from each lot. The results will be found in table 2. The kernels from the unsound corn sample weighed only 84 percent of those from the sound corn, and seemed to be lower in protein and oil content.

The effect of Nigrospora infection on the nutritive value of corn was tested with reference to protein and to energy. For the protein tests, three experimental rations were made up. Two of the rations contained 80.57 and 86.81 percent of the sound and unsound corn, respectively, as the sole source of protein, together with vitamin and mineral supplements. They were

equated with reference to protein and energy. The third, or diluting, ration contained no corn at all, but the same mineral and vitamin supplements as the other two, with enough starch, sugar and corn oil to furnish approximately the same gross energy per gram.

The rations for the energy tests contained 66.00 and 66.86 percent of

TABLE 3. COMPOSITION OF THE EXPERIMENTAL RATIONS USED IN THE PROTEIN AND THE ENERGY STUDIES WITH SOUND AND FUNGUS-DAMAGED CORN

Ingredients	Protein studies			Energy studies	
	Sound corn ration	Unsound corn ration	Diluting ration	Sound corn ration	Unsound corn ration
	percent	*percent*	*percent*	*percent*	*percent*
Casein	—	—	—	20.00	20.35
Sound corn	80.57	—	—	66.00	—
Unsound corn	—	86.81	—	—	66.86
Salt mixture 446	4	4	4	4	4
NaCl	1	1	1	1	1
Vitaminized starch[a]	5	5	5	5	5
Wood flock[b]	—	—	1.7	—	—
Starch	6.51	—	38.6	2	0.43
Corn sugar (cerelose)	—	—	38.7	—	—
Sucrose	—	—	5	—	—
Wheat germ oil	0.5	0.5	0.5	0.5	0.5
Cod-liver oil	1.5	1.5	1.5	1.5	1.5
Corn oil	0.92	1.19	4	—	0.36
Total	100.00	100.00	100.00	100.0	100.00
Protein content, pct.	7.31	7.12	0.29	21.88	22.31
Energy in Cals. per gm.	3.950	3.930	3.778	4.280	4.227

[a] Containing all of the known members of the B-complex except biotin and folic acid.
[b] Obtained from Brown Company, Portland, Maine.

sound and of unsound corn, respectively, and were supplemented, not only with vitamins and minerals, but also with 20 percent of casein. They were, therefore, nutritively complete, closely similar in gross energy content by actual determination in the bomb calorimeter, and possibly different only in the extent of utilization of the contained energy, two-thirds of which, approximately, was provided by the two samples of corn. The composition of all rations is given in table 3.

A paired-feeding technic was used throughout these experiments. In the energy tests, paired rats were fed equal amounts of their respective diets and the relative energy values were judged by the gains in body weight pro-

duced and by the gross energy content of the pooled carcasses produced on the two diets. In the protein tests, considerable differences in the live weight of rats within each pair were not allowed to develop. As soon as a tendency for a difference in weight appeared, the ration of the rat gaining the faster was diluted with the dilution ration above described, approximately nitrogen free, to the extent required to maintain equality of weight within the pair. The caloric intakes of pair-mates were thus maintained equal, and the protein intakes were adjusted to promote equal body weight gains. Differences in the protein quality of sound and unsound corn were, under these conditions, inversely proportional to the amounts of dietary protein required for equal gains in body weight. As in the energy tests, the carcasses of the rats at the termination of the feeding test were pooled for each of the two rations, and, in this case, analyzed for total nitrogen.

The rats were started on feed at weights of about 50 to 55 gms. and were continued on experiment for 30 days in the energy test and for 42 days in the protein test. There were 12 pairs of rats in the former test and 12 in the latter. The digestibility of dietary nitrogen or of dietary energy was determined in each experiment in a 7-day collection period on constant intake of food, a marker (Fe_2O_3) being used to separate the experimental feces. At the termination of the feeding periods, the rats were killed with ether, the body lengths from tip of nose to root of tail measured with the body under a standard tension, and the empty body weights determined. The latter weights were used in computing total gains. The carcasses of the experimental rats were frozen, ground finely, composited in each of the two tests according to the ration fed, and samples taken for analysis for total nitrogen in the protein test, and for gross energy in the energy test.

Experimental Results

The average experimental results for both tests are presented in table 4. The statistical significance of the differences between averages is indicated by the number of "pairs conforming" with the relationship between the respective averages. Thus, in the energy test, the final body length averaged 191.5 mm. for the rats raised on the sound corn diet, and 187.6 mm. for the rats fed on the unsound corn diet. Of the 12 pairs of rats on experiment, 10 showed a greater body length for the rat on the sound corn ration and only 1 pair showed the opposite. In one pair the body lengths were equal. Hence, the number of pairs conforming with the relation between average body lengths is 10.5.

Surprisingly, the palatability of the nigrospora-infected corn was significantly better than that of the sound corn.

The digestibility both of nitrogen and of energy was lower for the un-

sound corn than for the sound corn, the depression amounting to 3.5 percentage units for nitrogen and 0.7 percentage units for energy. Tested by Student's (1925) method, the probability that a random combination of the

TABLE 4. AVERAGE RESULTS OF THE PROTEIN AND THE ENERGY TESTS

Diet	Number of rats	Days on test	Average food intake, gms.	Gain in body weight		Final body length	
				Average, gms.	Pairs conforming	Average, mm.	Pairs conforming
The Protein Test							
Sound corn	12	42	292	30.4	5.5	164.9	6.5
Unsound corn	12	42	292	29.6		164.6	
The Energy Test							
Sound corn	12	30	306	112.8	9.5	191.5	10.5
Unsound corn	12	30	308	107.3		187.6	

TABLE 4, *continued*. AVERAGE RESULTS OF THE PROTEIN AND THE ENERGY TESTS

Diet	Digestibility of protein or of energy		Ratio of digestible nitrogen intakes		Composition of composite carcasses	
	Average, percent	Pairs conforming	Average	Pairs conforming	Protein, percent	Energy, Cals./gm.
The Protein Test						
Sound corn	81.7	11.5	1	9	2.87	—
Unsound corn	78.2		0.956		2.84	—
The Energy Test						
Sound corn	91.5	9.5	—	—	—	2.434
Unsound corn	90.8		—		—	2.330

uncontrolled factors in the experiment would have produced average differences as large or larger than these is less than 0.0001 for the protein test ($t = 6.51$) and 0.0038 for the energy test ($t = 3.32$). These probabilities are so small that they can be neglected, and the conclusion may be drawn that the

infection of corn with *Nigrospora oryzae* depresses the digestibility of both the nitrogen and the energy of this grain.

In the protein test, the ratio of digestible nitrogen intakes in the two diets required for the promotion of equal body-weight gains averages 1 for the sound corn to 0.956 for the unsound corn, and 9 of the 12 pairs conformed with this relationship, indicating that 0.956 gm. of digestible nitrogen from the unsound corn is the nutritive equivalent of 1 gm. of digestible nitrogen from the sound corn. The probability of a fortuitous outcome is only 0.017 ($t = 2.46$). Hence, the conclusion seems justified that the digestible nitrogen of the unsound corn is somewhat higher in the promotion of growth than the digestible nitrogen of the sound corn. The average nitrogen contents of the carcasses of the two series of rats are practically the same, 2.87 and 2.84 percent, testifying to the validity of the above conclusion. This anomalous result may be accounted for by a greater proportion of germ to endosperm proteins in the unsound corn, due to an inhibition of kernel growth (see table 2).

The ratio of intakes of total nitrogen by the two groups of rats was practically 1 to 1, namely, 1 to 0.995 for the sound and unsound corn, respectively. Four pairs favored the sound corn in this respect, and 8 pairs favored the unsound, but actually no statistically significant difference was demonstrated. Apparently, the poorer digestibility of the nitrogen of the unsound corn is compensated for by the poorer utilization in metabolism of the digestible nitrogen of the sound corn.

On equal intakes of gross energy, the rats subsisting upon the unsound-corn ration gained 4.9 percent less than the rats on the sound-corn ration on the average, and attained a body length averaging 2.0 percent less (see table 4). These average differences are highly significant statistically, with t values of 2.31 and 3.98 respectively, and probabilities of 0.021 and 0.001 The energy content of the carcasses of the rats at the termination of the feeding test averaged 2.434 Cals. per gram for the rats on sound corn, and 2.330 Cals. per gram for the rats on the unsound corn. The energy of the unsound corn was definitely, if only slightly, less well utilized by the growing rat than the energy of the sound corn.

Only a small part of this difference in energy utilization can be accounted for by a difference in digestibility. The average coefficients of digestibility of energy were 91.5 percent for the rats on the sound corn ration, and 90.8 percent for the rats on the unsound corn ration. As stated above, this difference, though small, is statistically significant.

Conclusions

Corn kernels infected with *Nigrospora oryzae* to the extent of 53 percent

by naked eye inspection average 84 percent as heavy as comparatively sound corn of the same hybrid and grown in the same field in the same year. Their chemical composition is not greatly different than that of sound corn, though they contain somewhat less nitrogen and ether-soluble constituents.

The nitrogen of the nigrospora-infected corn is definitely less digestible by the growing rat than that of sound corn, but the digestible nitrogen is somewhat better utilized in metabolism, possibly because of a greater proportion of nitrogen from the corn germ. These two opposite effects approximately neutralize each other, so that 1 gram of nitrogen in the damaged corn is the nutritive equivalent of 1 gram of nitrogen in the sound corn.

The energy of the nigrospora-infected corn is definitely, if only slightly, less digestible than that of sound corn, and appears to be less available in the metabolism of the growing rat.

Literature Cited

Dungan, G. H., J. H. Bigger, A. L. Lang, Benjamin Koehler and R. W. Jugenheimer. 1945. Illinois Hybrid Corn Tests. Ill. Agric. Expt. Sta. Bul. 517: 227–256.

Mitchell, H. H. and Jessie R. Beadles. 1940. The Impairment in Nutritive Value of Corn Grain Damaged by Specific Fungi. Jour. Agric. Res., 61: 135–142.

Student. 1925. New Tables for Testing the Significance of Observations. Metron., 5: 105–120.

NEWS AND NOTES

The next meeting of the American Society of Animal Production will be held at the Hotel Sherman in Chicago on November 28 and 29, 1947, with a dinner for the honor guest on November 30. Abstracts of papers to be presented at this meeting must be in the hands of the Secretary, Dr. W. G. Kammlade, by September 10. Members are reminded that abstracts must not exceed 250 words in length, that they should be typed (double spaced), and the ribbon and one carbon copy submitted. They must be typed on forms supplied by the Secretary for that purpose, in accord with instructions he has already mailed to all members. Abstracts must be summaries of results and conclusions, and members should consult previous issues of the JOURNAL and have their abstracts typed in a form corresponding to that used in these published abstracts. For information concerning chairmen of Sectional Programs at the next annual meeting, members are referred to page 103 of the February 1947 issue of the JOURNAL OF ANIMAL SCIENCE.

The Western Branch of the American Society of Animal Production will hold its next meeting at the University of California at Davis on August 26 and 27, 1947. This will be a joint meeting with the Western Division of the American Dairy Science Association. Members of the Society should note that this is a slight shift from the dates of August 27 and 28 announced in the May issue of the JOURNAL OF ANIMAL SCIENCE.

Proposed Amendment of Constitution

It is proposed that Article II, Section 4, of the Constitution of the American Society of Animal Production be amended as outlined below:

This Section now reads:—

"Section 4. Forfeiture.

"A membership or subscription is void if not paid by January 1 of the calendar year to which it applies. Reinstatement of membership forfeited because of failure to pay dues takes place automatically as soon as delinquent dues are paid."

It is proposed to amend the above section to read as follows:—

"Section 4. Forfeiture.

"A membership is void if dues are not paid by January 1 of the calendar year to which they apply. Members whose dues are paid after January 1 but before July 1 of the calendar year shall be assessed $1.00 (one dollar) additional. After July 1 reinstatement of membership will be made only on payment of current dues plus a reinstatement fee of $5.00 (five dollars). A person who was once a member may not be proposed as a new member to avoid payment of the delinquency fee.

Subscriptions to the JOURNAL OF ANIMAL SCIENCE shall be on a volume basis only and shall expire with the calendar year unless renewal or notice of intention to renew is received by that time."

This proposed amendment will be discussed and voted upon at the forthcoming meeting of the Society in Chicago.

P. B. Pearson, professor of animal nutrition and nutritionist for the Agricultural Experiment Station at the Agricultural and Mechanical College of Texas has been appointed Dean of the Graduate School at the same institution.

Joe B. Johnson, veteran of the South Pacific, has been appointed Assistant Professor of Animal Husbandry, Oregon State College, effective July 1, 1947. He will have the judging work in the college and beef cattle production in the experiment station.

Ralph Bogart of the University of Missouri, Department of Animal Husbandry, has accepted appointment as Professor of Animal Husbandry, Oregon State College, effective

September 1, 1947. He will lead in the genetics investigations. This is a new position in the department.

Ralph W. Phillips, of the Food and Agriculture Organization of the United Nations, and Harold H. Cole and Max Kleiber of the Animal Husbandry Division, University of California, attended the XVIIth International Physiological Congress in Oxford, England, during the period July 22 to 25, 1947.

Richard T. Allman, of Toronto, Canada, who received his Ph.D. at Cornell University in 1941, and did agricultural work in Greece and China in recent years, was appointed to the post of Animal Nutrition Specialist in the Animal Industry Branch, Agriculture Division, Food and Agriculture Organization of the United Nations, Washington, D. C., effective July 14, 1947.

Douglas H. K. Lee, head of the Department of Physiology, University of Queensland, Brisbane, Australia, is doing a special assignment for the Animal Industry Branch, Agriculture Division, Food and Agriculture Organization of the United Nations, Washington, D. C., during the period June–September, after which he will work in the Department of Geography, Johns Hopkins University, Baltimore, Md., for four months before returning to Australia.

John E. Foster, formerly of the Animal Husbandry staff at North Carolina State College, was appointed head of the animal husbandry staff at the University of Maryland, effective August 15.

Wayland Rhoads, who has been in military service for several years with the War Department in Europe, has resigned his position as extension animal husbandman at the University of Kentucky.

George W. Litton, extension animal husbandman at the Virginia Polytechnic Institute, has been made acting head of the department during R. E. Hunt's temporary absence as a member of an agricultural mission employed by the Syrian government.

S. J. Brownell, extension professor of animal husbandry at Cornell University, has returned from a year's service with the A.M.G. in Germany.

Paul Swaffer, formerly extension animal husbandman at the Virginia Polytechnic Institute, and more recently manager of the Atlantic Rural Exposition, has been appointed field representative for the American Hereford Association with headquarters at Memphis, Tenn.

R. H. Ruffer, professor of animal husbandry and dairying at the North Carolina State College, where he served for 28 years, retired July 1, 1947.

Ray H. Means, Associate Animal Husbandman and Associate Professor at the Mississippi State College, has been made superintendent of the livestock substation of the Mississippi Agricultural Experiment Station at Oakley.

Phi W. Ljundahl, formerly Extension Animal Husbandman, Kansas State College, resigned June 1 to become southwestern field representative for the American Aberdeen-Angus Breeders' Association.

George C. Humphrey of the University of Wisconsin, died on June 18 at the age of 72, after a period of service extending over 39 years.

E. F. Moody of the animal husbandry staff, South Dakota State College, has resigned to become field representative for the Heart of America Aberdeen-Angus Association.

C. R. Fowler, animal husbandry graduate of Oklahoma A & M College and World War II veteran, became commercial field representative of the American Aberdeen-Angus Breeders' Association, effective June 1.

William B. Lutz, a graduate of Michigan State College, has been appointed Extension Specialist in Livestock for the upper peninsula of Michigan.

L. A. Kauffman, formerly secretary of the Ohio Cooperative Wool Growers' Association, has been appointed to the resident teaching staff in animal husbandry at Ohio State University.

T. C. Byerly, formerly head of the poultry section has been made Chief of the Animal Husbandry Division, Bureau of Animal Industry, USDA. Henceforth, Hugh C. McPhee, the former Chief of the Division, will devote full time to his duties as Assistant Chief of the Bureau in charge of research.

Herbert Carrier, an animal husbandry graduate of Oklahoma A & M College, has been named superintendent of beef cattle and instructor in animal husbandry at Southwestern Louisiana Institute, Lafayette, La., effective September 1.

Charles F. Curtis, Emeritus Dean of Agriculture at Iowa State College, died on July 30, 1947.

V
3
A
U
4
X